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## STUDIES FROM THE PSYCHOLOGICAL LABORATORY OF OBERLIN COLLEGE

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# THE HAIR FOLLICLE AND THE SENSE OF PRESSURE

BY

R. H. STETSON

It has been assumed that the end-organs for pressure are located at separate points, like those of warmth and cold. Careful exploration of the skin by Goldscheider and v. Frey[1] revealed separate spots where the sense of pressure reaches a maximum. The intervening skin is also sensitive to pressure, but that may be the result of the transmission of the stimulus through yielding skin structures to the nearest 'pressure spots.' The actual end-organs for warm and cold are in doubt, but it has seemed easy to determine the end-organs for pressure. On hairy areas maximum sensitiveness to pressure occurs at a spot to the 'windward' of the hair, and is evidently due to the stimulation of the hair follicle. The follicle lies embedded in the skin at an angle so that the 'pressure spot' occurs over the follicle a millimeter or so from the point where the hair emerges. It is easy to see the relation, for stimulation of the 'pressure spot' moves the hair shaft.

The histology of the hair follicle reveals an elaborate innervation which might well mediate an important cutaneous quality. A double innervation has been described and is a commonplace in the text books.[2] A detailed account of the innervations of the follicle with references to the original studies and with drawings of the structures is given by Prenant and Bouin.[3] They speak of the neural ring of non-medullated fibres which originate from a nerve entering the follicle at the level of the opening of the

[1] A. Goldscheider, Ges. Abhandl. I, 1898. v. Frey, Vorles. u. Physiol. 1894. v. Frey, Ergebnisse d. Physiol. (Asher u. Spiro) 1913. Bd. 13, S. 96. Physiol. d. Sinnesorgane d. mench. Haut. II, Der Drucksinn.

[2] Stewart, Manual of Physiol., 1910; Howell, Physiol., 1896, p. 260; Bailey, Histol., 1910, p. 365; Ferguson, Hor. Histol., 1905, p. 225; Piersol, Nor. Histol., 1910, p. 328.

[3] Prenant et Bouin, Traité d'Histologie, 1911, p. 624 ff.

sebaceous glands. This neural ring is double and lies well outside the vitreous membrane. On the outside surface of the vitreous membrane at the level of the neural ring and extending below it are a number of enlarged, spatulate endings, possibly derived from the fibrils of the ring. There is also an innervation of the root proper of the hair, nerve fibres which enter the papilla of the follicle at the lower end of the follicle. Szymonowicz[4] has made a detailed study of the innervation of the human hair by the methylen blue method, and has been able to reconcile the statements of previous authors. He speaks of the neural ring and the flattened endings on the outside of the vitreous membrane just below the sebaceous glands, and of the nerve entering the papilla of the hair. His detailed drawings give an idea of the form of the nerve endings and of their distribution. The material used was freshly excised from the eyelid and from the lower lip. The studies of the human hair follicle have been confined to a few localities on the human body.

The tactile hairs of many mammals are undoubtedly important touch organs, and have been studied. Their innervation is not unlike that of the human hair; this increases the probability that the human hair is an important tactile organ.[5]

Actual experiment shows that the hair itself is an important factor in the pressure sense. Vincent quotes Sherrington: "On 9 sq. cm. of skin from which the hairs have been shaved, the liminal stimulus was found to be 36 mgm, whereas, on the same surface before it was shaved, 2 mgm was the liminal stimulus." And it is well known that the hair itself is more sensitive to pressure than the 'pressure spot' near the hair.

Following v. Frey, Thumberg[6] and others speak of the hair acting "as a lever, in that the neural stimulation may be described as a moment of rotation wherein the surface of the skin acts as

[4] L. Szymonowicz, Ub. die Nervenendigungen in d. Haaren d. Menchen, Archiv. f. mikro. Anat. 1909, Bd. 74, S. 622-634.

[5] S. B. Vincent, The tactile hairs of the white rat, J. Comp. Neurol. v. 23, 1913, p. 1-38. J. E. Eckert, The innervation of the integument of Chiroptera, J. of Morphol., 1914, v. 25, p. 315-320.

[6] Nagel's Handb. III, 1905, S. 664.

a fulcrum." This notion of the hair as a lever of the first class in which the epidermis at the point of emergence acts as a fulcrum so that the movement is transmitted to the follicle has been commonly accepted. It is apparent that the skin does act as a fulcrum for the tactile hairs of animals when they are moved, and something like that must take place when the human hair is erected by the muscles of the hair follicles. Nevertheless the observation is inaccurate when applied to the human hair as a tactile organ.

Despite this general acceptance of the hair follicle as the pressure organ in hairy areas, there are certain acts not in accord. It is hard to understand why the scalp and the bearded area of the face should not be far more sensitive, if they are crowded with pressure organs. Moreover the 'pressure spots' unlike the warm and cold spots, are but points of maximum sensitiveness, and the skin is everywhere sensitive to pressure. Murray[7] speaks of the difficulty of a precise localization of the 'pressure spots,' and of the apparent existence in the intermediate areas of other spots of approximately equal sensitiveness, and of the impossibility of reproducing the granular sensation by electrical stimulation of the verified spots. The extreme delicacy of the response when the skin is lightly touched with cotton, etc. makes it doubtful if there is transmission to such deep-lying structures as the follicles. Merkel[8] hazarded the guess that certain simple end-organs scattered in the skin as well as about the hair follicles were "touch corpuscles." And certainly Murray's statement: "The greater efficiency of pressure over the hair bulb in the production of the pressure sensation is probably due to the mechanical effect through the grinding down of the comparatively solid follicle upon the underlying endings" is worth noting. There is good reason to consider his assertion that "the so-called granular pressure is not in itself an element but is a complex of deeper pressure with contact. . . ."[9]

[7] E. Murray, Qual. Anal. of Tickle, Am. J. Psy. 1908, v. 19 (3), p. 299.

[8] F. R. Merkel, Tastzellen in Tastkörperchen bei d. Hausthieren u. b. Menchen, Archiv f. mikro Anat. 1876, Bd. 11, S. 647.

[9] Murray, *ibid.*

### PROBLEM

It is possible to investigate the function of the hair follicle as an end-organ for the sense of pressure by two methods:

1) The neural endings of the follicle may be removed, and the effect on the sensitiveness of the hair itself and of the adjacent areas studied;

2) The pressure sensitivity of areas denuded of follicles may be investigated.

Before operating the hair follicle, preliminary studies of the movements of the follicle and the resulting sensations were made. The skin, carefully scrubbed and softened, was moistened with a little water and glycerin, and examined with a Zeiss binocular erecting microscope magnifying c.9 times. A strong red light was used for illuminating; unlike the white light the red light is not reflected, rendering the surface opaque, and it penetrates the skin to a slight depth. By this means the hair-shaft of a dark-haired subject may be traced about two millimeters into the skin, and the movement of the follicle noted when stimulation is applied.

On moving the hair on back of hand or on forearm, under such conditions, it is easy to see that the description of the hair as a lever of the first class is inaccurate. The lower end of the follicle is far more firmly fixed than the surface where the hair emerges, and the movement affects the lower end little if at all, while the upper part of the follicle and the skin at the point of emergence undergo considerable deformation. The hair is a lever of the second class, with the fulcrum at the lower end of the follicle, rather than a lever of the first class with the fulcrum at the surface where the hair emerges. The hair is like a willow shoot deeply rooted in light sand; when the shoot is moved, the part just below the surface, and the surface layer of the sand itself are stirred, but the root of the willow shoot is not moved.

For a careful study of the movements of the follicle including the papilla, the hairs of the scrotum were used; the skin is thin and transparent, the follicles large and single, and the papilla clearly defined by a pigmented spot. On the scrotum as else-

where, the movement of the skin about the point where the hair emerges is a most striking item in the stimulation of the hair. The skin may be fixed with collodion, and the lower end of the follicle moved two millimeters without causing sensation. This was verified by repeated observations on several hairs on each of three subjects, two of whom were trained observers.

When traction is exerted on the hair it is easy to see that the lower part of the follicle is not the significant point; the end of the follicle may be moved back and forth two or three millimeters without the sensation of pulling being noted. On the other hand, if the skin is fixated by putting a blunt point, or a hook partly encircling the hair, into the pit of the hair, a slight traction is quickly perceived; much greater traction must be exerted if the skin is not fixated. This indicates that the pressure sensations are mediated by the upper part of the follicle, and possibly by the skin surface at the point of emergence. These observations were verified on several hairs on each of five subjects, two of whom were trained observers.

## OPERATION ON THE HAIR FOLLICLE

### *Removal of the lower part of the Follicle.*[10]

The area selected for the operation was the anterior portion of the scrotum near the median line. The surface is fairly sensitive to pressure, and the localization is about as good as on the forearm. The follicles are easily seen and operated. They are single and widely separated, as in no other part of the body. A strong red light was used, and the work was done under the binocular with a magnification of c. 9 times. To fixate the follicle, a No. 14 or 16 needle (f.n. in Fig. 1) in which a minute bend had been made was passed through the skin, under the follicle at right angles, and out on the other side, pinning the follicle in a tiny stitch in the skin (Figs. 1 and 2). The follicle lay in the bend of the needle (Fig. 2). Without local anesthesia, a transverse in-

[10] Mr. C. C. W. Nicol, Assistant in the Oberlin Laboratory 1912-13, assisted in the development of a rather difficult and exacting technic, and did a part of the tedious work of operating and testing the hair follicles.

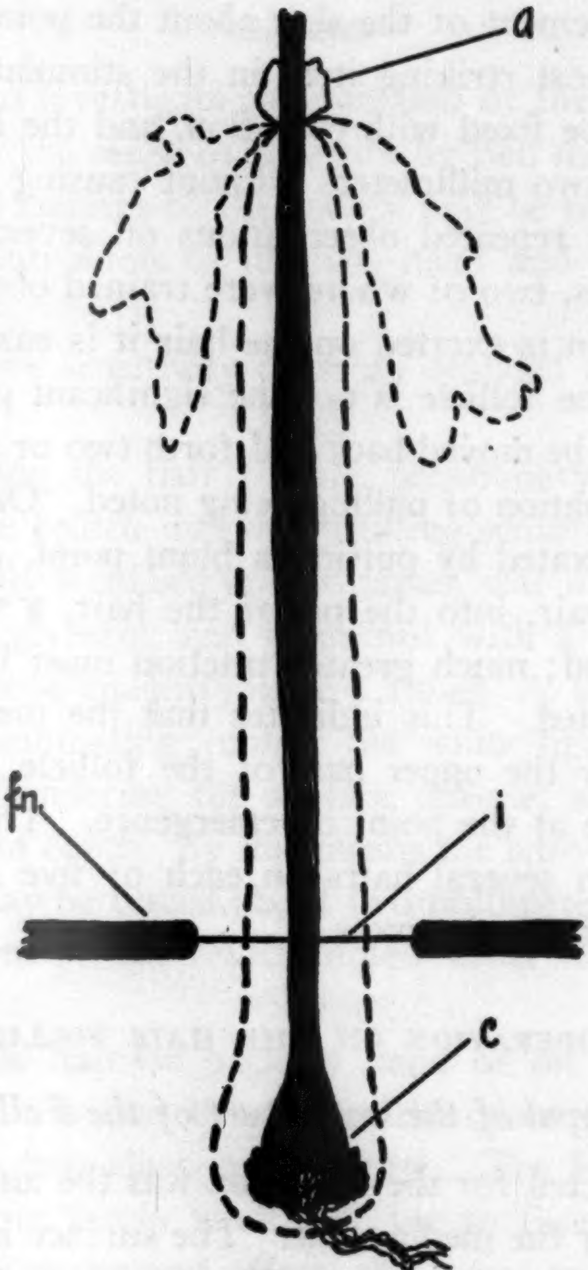



Fig. 1

cision was made just over the needle (i in Figs. 1 and 3) with a small scalpel ground out of a needle; then the papilla (c, in Fig. 3) with about half a millimeter of the follicle was snipped off (at d in Fig. 3) with scissors ground to fine slim points. The severed portion was removed with fine tweezers. It is unnecessary to snip off the lower part of the follicle; dissecting it loose breaks all connections; but for the sake of certainty the lower part of the follicle was always removed. The operations were done with the usual precautions, without local anesthesia. The tissues are resistent to infection and the wounds heal very rapidly. There

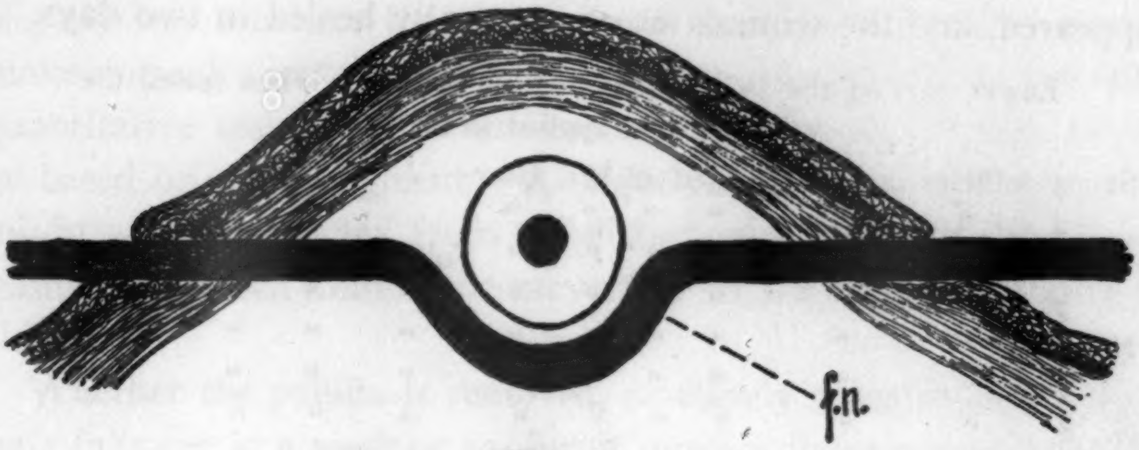



Fig 2

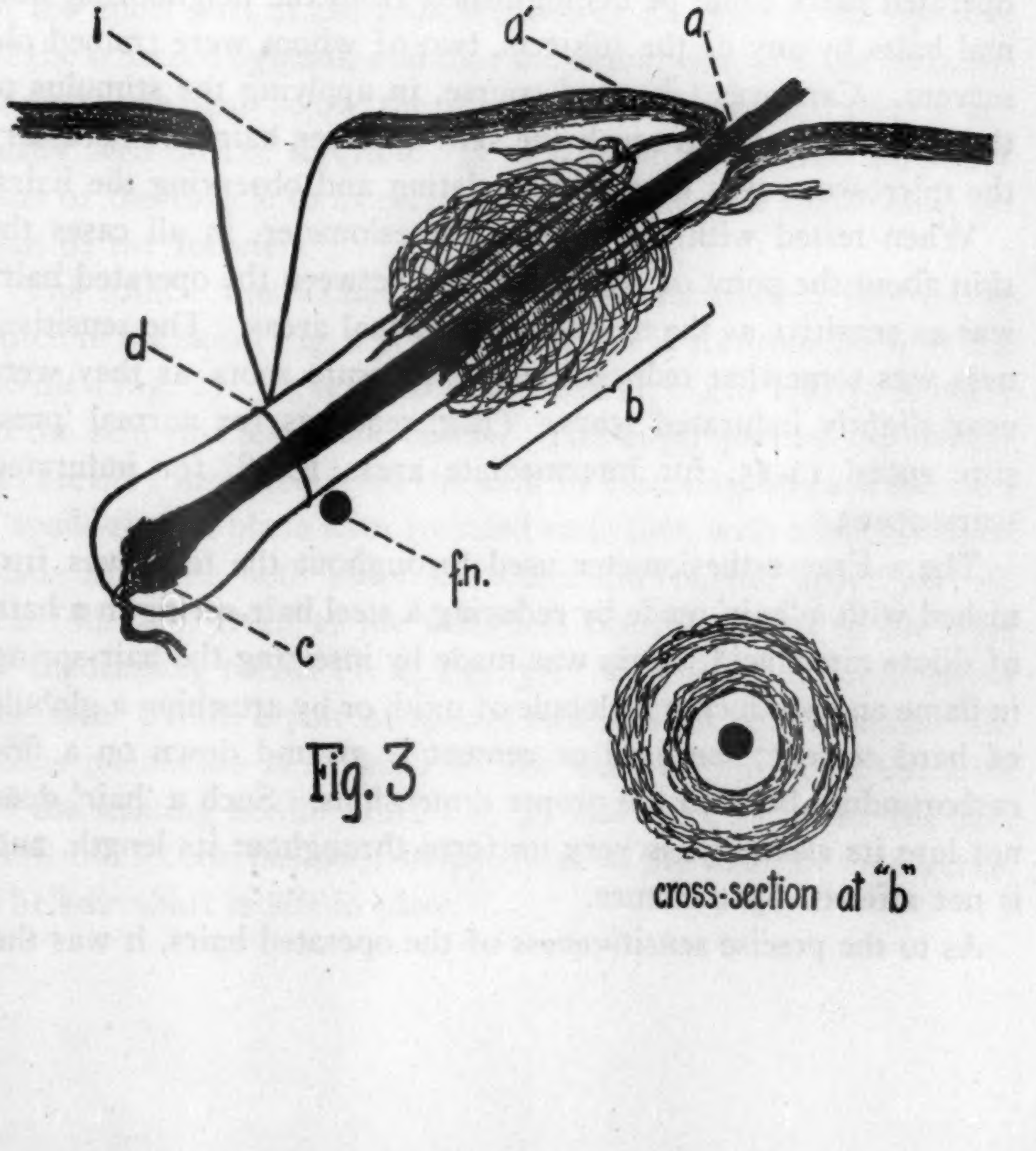



Fig. 3

cross-section at "b"

was a slight induration about the scar, but the reaction had disappeared, and the wounds were practically healed in two days.

Lower part of the follicle removed, on scrotum: when tested the stimulus was applied to the hair.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| St. | 3 | follicles | operated, | tested | 48 | hrs. | later | | | |
| | 2 | " | " | " | " | " | " | | | |
| L. | 5 | " | " | " | " | " | " | Follicles | in a | group |
| | 7 | " | " | " | " | " | " | " | " | " |
| N. | 6 | " | " | " | " | " | " | " | " | " |
| | 7 | " | " | " | " | " | " | " | " | " |
| S. | 8 | " | " | " | " | " | " | " | " | " |
| | 1 | " | " | " | " | " | " | " | " | " |
| Ni. | 8 | " | " | " | " | " | " | " | " | " |
| | 1 | | | | | | | | | |
| | 48 | | | | | | | | | |

In every case every hair was sensitive after the operation, and there was no difference in quality or localization whereby the operated hairs could be distinguished from the neighboring normal hairs by any of the subjects, two of whom were trained observers. Care was taken, of course, in applying the stimulus to the hair shaft, not to touch the skin or other hairs; if necessary the microscope was used in stimulating and observing the hairs.

When tested with the v. Frey esthesiometer, in all cases the skin about the point of emergence and between the operated hairs was as sensitive as the neighboring normal areas. The sensitiveness was somewhat reduced on the 'pressure spots' as they were near slightly indurated scars. (E.g. readings for normal 'pressure spots' 14-15, for intermediate areas 16-18, for indurated scars 20-23.)

The v.Frey esthesiometer used throughout the tests was furnished with a 'hair' made by reducing a steel hair-spring in a bath of dilute nitric acid. A tip was made by inserting the hair-spring in flame and producing a globule of oxid, or by attaching a globule of hard cement; the oxid or cement is ground down on a fine carborundum hone to the proper dimensions. Such a 'hair' does not lose its elasticity, is very uniform throughout its length, and is not affected by moisture.

As to the precise sensitiveness of the operated hairs, it was the

judgment of both experimenters that the operated hairs were slightly less sensitive than the normal hairs; the subjects could make no such discrimination. It is of course difficult to get any quantitative tests for stimulation of a hair, and nothing could be based on this judgment. A slight reduction of sensitiveness might well be expected from the disturbance and from the slight induration which limited the movement of the follicle and of the skin.

Whether the papilla is removed, or merely dissected loose, the hair falls out in a week or so; but it remains in place long enough for tests. The time (two days) between operation and test is of course much too short for any regeneration of the nerve fibrils.

### *Removal of the Upper Part of the Follicle*

It is agreed that the nerve supplying the elaborate innervation of the upper part of the follicle enters at the level of the opening of the sebaceous glands, and that the neural ring and the flattened endings are just below the glands. The sebaceous glands are easily seen on the scrotum. It is possible to remove the upper part of the follicle so as certainly to eliminate the upper innervation of the follicle.

The follicle was fixated by pinning it transversely into a tiny stitch in the skin (Fig. 1); the follicle lies in a minute bend of the needle (Fig. 2). A transverse incision (i, Fig. 1 and 3) is made in the skin just above the needle. The upper part of the follicle is carefully dissected from the skin by inserting beneath the skin a spade-shaped blade with rounded end; then with a hook-shaped blade sharp on both inner and outer curves, the upper part of the follicle is freed at the sides and beneath, down to the level of the fixating needle (f. n., Fig. 3). Care is taken not to pierce the skin. With a pair of special tweezers the tough, elastic vitreous membrane is stripped off the hair, beginning at the level of the fixating needle (f.n., Fig. 3) and working under the skin until the follicle has been stripped out to the point of emergence. The hair shaft is left in place.

The knives were ground from No. 5 needles. The tweezers were made of two "crow-quill" steel pens carefully ground until the points are very slender. The four minute strips of steel were then bent at the tips until slightly hooked and ground sharp at the squared tips. These four prongs encircle the hair and strip away the follicle, but are elastic enough not to tear the hair.

In this fashion the follicle is cleared away for about one-half its length; care is taken not to disturb the lower end of the follicle. The transverse incision is 1.5-3 mm. from the emergence point and the skin about the hair is intact. The reaction subsides in a day or so and the wound heals in a very short time, leaving the hair uninjured—unlike the first operation.

Removal of the upper part of the follicle on scrotum; when tested the stimulus was applied to the hair.

| | | | | | |
|---|---|---|---|---|---|
| St. | 1 | follicles; tested after | 48 hrs. | Sensation | nearly normal |
| | 1 | " " " | 48 " | " | decidedly subnormal |
| Ni. | 3 | " " " | 12 " | " | normal; after 48 hrs. normal |
| St. | 4 | " " " | 12 " | " | normal |
| P. | 1 | " " " | 12 " | " | normal |
| M. | 3 | " " " | 12 " | " | normal |
| | 1 | " " " | 12 " | " | decidedly subnormal; after 48 hrs. c. normal |
| K. | 5 | " " " | 12 " | " | normal; after 48 hrs. normal. Follicles in a group. |
| Ma. | 5 | " " " | 12 " | " | normal; after 48 hrs. normal. Follicles in a group. |
| M. | 4 | " " " | 12 " | " | normal |
| St. | 4 | " " " | 48 " | " | normal. These hairs were compared with normal hairs which had been scarified without injuring the follicle; no difference found. |
| K. | 4 | " " " | 12 " | " | normal; after 4 days, normal. |
| Ni. | 3 | " " " | 12 " | " | normal |
| | 1 | " " " | 12 " | " | slightly subnormal |
| L. | 1 | " " " | 12 " | " | decidedly subnormal |
| | 1 | " " " | 12 " | " | slightly subnormal |
| Ni. | 2 | " " " | 24 " | " | slightly subnormal |
| K. | 4 | " " " | 12 " | " | subnormal; 4 days after, subnormal. |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| S. | 1 | " | " | " | 48 | " | " | normal |
| | 1 | " | " | " | 48 | " | " | decidedly abnormal; scar tissue. |
| L. | 1 | " | " | " | 24 | " | " | normal |
| | 1 | " | " | " | 24 | " | " | slightly abnormal |
| T. | 2 | " | " | " | 24 | " | " | subnormal; 48 hrs. after, normal |
| Ma. | 2 | " | " | " | 24 | " | " | normal |
| K. | 1 | " | " | " | 24 | " | " | decidedly subnormal; 3 days after, slightly subnormal. |
| | 1 | " | " | " | 72 | " | " | normal |
| S. | 3 | " | " | " | 24 | " | " | sensation subnormal; 48 hrs. after, slightly subnormal. |
| L. | 1 | " | " | " | 48 | " | " | slightly subnormal |
| Ma. | 1 | " | " | " | 48 | " | " | slightly subnormal |
| | — | | | | | | | |

63 hairs operated on eight subjects.

Of these 63 follicles, 4 proved to be decidedly subnormal, though not insensitive; it is possible that in those cases the nerves of the skin were severed, or the formation of scar tissue involved the fibers supplying the skin about the hair.

From these results it is easily seen that there is a tendency to reduction of the sensitiveness of the hair when the upper innervation of the follicle is removed. In many cases this is not apparent on scrotal areas but it comes out more plainly on other parts of the body.

The lower arm has been much used for study of skin sensations. It is not entirely satisfactory for the present purpose, because it is difficult to find single hairs. On nearly all parts of the body the hairs are closely set in threes, one large hair with a small guard-hair on either side.

Removal of upper half of follicle on lower arm; when tested the stimulus was applied to the hair.

| | | | | | | |
|---|---|---|---|---|---|---|
| St. | 2 | follicles; | tested | after | 24 hrs. | Subnormal: 2 days after, subnormal. |
| | 2 | " | " | " | 48 " | Subnormal |
| Tu. | 2 | " | " | " | 48 " | Subnormal |
| M. | 1 | " | " | " | 6 days | Subnormal |

Removal of the upper half on upper leg, just above patella; when tested the stimulus was applied to the hair.

| | | | | | | |
|---|---|---|---|---|---|---|
| St. | 2 | follicles; | tested | after | 24 hrs. | Subnormal; 6 days after nearly normal. |
| | 2 | " | " | " | 24 " | Subnormal; 4 days after nearly normal. |

Removal of upper half of follicle on lower leg; when tested the stimulus was applied to the hair.

| | | | | | | |
|---|---|---|---|---|---|---|
| L. | 4 | follicles; | tested | after | 48 hrs. | Subnormal |
| | 2 | " | " | " | 4 days | Subnormal |
| M. | 3 | " | " | " | 48 hrs. | Subnormal |
| | 2 | " | " | " | 48 " | Subnormal |

The point of the hip, just outside the area of pubic hair is a good locality for testing hair follicles; the hairs are large, sparse, and single.

Upper half of the follicle removed on point of hip; when tested the stimulus was applied to the hair.

| | | | | | | |
|---|---|---|---|---|---|---|
| St. | 6 | follicles: | tested | after | 6 days, | Subnormal |
| M. | 2 | " | " | " | 4 " | Subnormal |
| | 3 | " | " | " | 2 " | Nearly normal |
| Ni. | 3 | " | " | " | 2 " | Subnormal |
| | 4 | " | " | " | 4 " | Slightly subnormal |
| L. | 2 | " | " | " | 4 " | Subnormal |
| | 2 | " | " | " | 4 " | Nearly normal |
| N. | 4 | " | " | " | 12 hrs. | Subnormal |
| Sh. | 5 | " | " | " | 11 days | Subnormal |
| L. | 1 | " | " | " | 6 " | Subnormal |
| M. | 1 | " | " | " | 2 " | Subnormal |
| | 1 | " | " | " | 2 " | Almost normal |

(The interval between operating and testing was lengthened because more time was needed for healing.)

In all these cases the removal of the upper part of the follicle, the quality of the hair sensation is not changed; the subjects are unable to discriminate between the operated hairs and the neighboring hairs. It is evident however that there is a decided reduction of the sensitiveness of the hairs operated on other parts than the scrotum. That this does not occur more often on the scrotum is probably due to the greater size and rigidity of the hair, and the greater mobility of the surface, whereby the movement of the hair-shaft produces a decided deformation of the skin.

*Removal of both Upper and Lower Innervations of the Follicle*

Although the preliminary experiments, and the removal of the lower end of the follicle indicate that the lower innervation of

the follicle has no influence on the pressure sensation, it is possible to argue that the pressure sensation remaining after the removal of the upper half of the follicle is not due to the deformation of the skin about the hair, but to the stimulation of the lower innervation. To test this, a number of hairs were subjected to both operations. The upper part of the follicle was removed, the wound allowed to heal, and then the lower part of the follicle was exsected. The hair was then little more than a bristle set in a mass of scar tissue.

Removal of upper and lower innervations of follicle on scrotum; when tested the stimulus was applied to the hair.

| | | | | |
|---|---|---|---|---|
| M. | 2 follicles; | tested 24 hrs. | after 2d operation. | Probably slightly subnormal. |
| | 4 " | " 24 " | " " " | Probably slightly subnormal. |
| | | 3 days | " " " | Normal |
| W. | 3 " | " 24 hrs. | " " " | Slightly subnormal |
| | 4 " | " 24 " | " " " | Slightly subnormal |

On stimulating such hairs, the sensation must come of course from the skin at the point of emergence. The scrotal hairs are well isolated, and there is little chance of diffusion of the stimulus to neighboring follicles. The experiments on three subjects show that the removal of both innervations gives the same result as the removal of the upper innervation. There is every reason to assume that the papilla is not a sensory end-organ of any sort.

### *Removal of the Entire Follicle*

When the follicles are entirely removed from a hairy surface, any response to light pressure must be due to end-organs in the skin surface.

Areas were selected on the scrotum where the single follicles are well defined; the skin is transparent and it is possible to locate and extirpate every follicle with certainty. The follicles were removed entire. The wounds were small, there was very little reaction (no local anesthesia was used) and the healing was very rapid. From 10 to 20 follicles were removed from each territory.

M. An area 2.5 sq. cm. was cleared; tested 24 hrs. after with probe showed some insensitiveness. Three days after, tested carefully with the v. Frey apparatus it was impossible to detect any change of the intermediate areas within the denuded territory. The scars themselves were slightly less sensitive.

K. 3 sq. cm. Tested three days after clearing. With v. Frey apparatus no difference could be detected save in the scars which were much below normal.

S. 2 sq. cm. Tested 12 hours after clearing. 'Pressure spots' of normal territory show lower threshold (14) than intermediate areas of either denuded or normal territories. Calls stimulation of normal 'pressure spot' "hair." Intermediate areas give the same reading (17) in normal and denuded skin. Tested after six days, the 'pressure spots' of normal territory have lowest threshold (15); intermediate areas in both normal and denuded skin give 17. The pressure spots of the normal areas are easily deformed. The scars of denuded area are thickened, and not easily deformed, and give a reading of 19-22.

L. 3 sq. cm. Tested 8 days after clearing. No difference could be detected between normal and denuded territories, save that the slightly indurated scars were less sensitive. The dilute alcohol used for asepsis had tanned and thickened all the skin slightly.

Ma. 3 sq. cm. Tested 5 days after clearing. No difference between the normal and denuded territories, save that the scars which do not deform easily, are not as sensitive as other areas. The normal 'pressure spots' are no more sensitive than the intermediate areas; they do not deform as easily as in the case of S.

W. 2 sq. cm. Tested 10 days after clearing. No difference between the normal and denuded territories, and threshold is not lower for the normal 'pressure spots,' which do not deform easily. The thickened scars are relatively insensitive and do not deform readily.

In all these cases, care was taken to test out several localities within and without the denuded territory, and to select places well within the denuded territory, so that there might be no possi-

bility of diffusion of the stimulus to normal end-organs. The tissue of the scrotum is so yielding and flexible that such transmission is improbable in any case.

In these cases the power of localization, the threshold for light touch and for tickle all seemed the same in the normal and in the denuded territories.

In the various operations on the hair follicle it is noteworthy that there are no pain endings found in the follicle. On the scrotum there are no pain endings to be found in the subcutaneous fibres. On the other surfaces, many pain endings are met with in the subcutaneous tissue. The scrotum gives but little pain sensation; the lower arm, lower leg, and point of hip are about equally sensitive; the leg just above patella gives very acute pain sensation and few subjects are able to bear operations there without local anesthesia. The differences in the sensitiveness to pain of different localities is very striking.

### *Examination of Extensive Scars*

A number of large scars where the skin had been destroyed were carefully examined. The area was first searched for traces of follicles, which can easily be detected when the surface is rubbed down, moistened, and examined under a binocular with red light. Nineteen scars on 17 subjects were studied. The scars occurred on various parts of the body but mainly on the lower leg and lower arm. In most cases the threshold for pressure was below that of the bordering area; this varied somewhat with the thickness of the scar epidermis. Localization did not seem to be affected. Two scars which were heavily indurated and covered with a thickened skin, were quite insensitive, and did not give the results of the other 17.

An attempt was made to imitate the hair sensation on these 19 scar areas. Artificial 'hairs' were made 1) by inserting a fine elastic needle into the epidermis, 2) by cementing onto the scar surface a bit of hair-spring or fine wire bent at the base into a tiny foot. A stimulator consisting of a bit of reduced hair-spring tipped with a little ball of collodion was applied with quick taps.

In 17 cases, on as many subjects, it was easy to imitate hair sensations, so that the subject could not tell the false 'hairs' from the normal hairs of the bordering areas. The confusion was complete.

Artificial 'hairs' were mounted on three trained subjects on the back of the hand between the normal hairs. It was impossible to discriminate the false from the normal hairs.

Artificial 'hairs' were mounted on three trained subjects on the hairless palmar area (at ball of thumb on outer edge of hand) near the hairy area, and compared with normal hairs. Subjects were quite unable to distinguish between the false and the normal hairs.

These experiments with artificial hair sensations on scars and on the hairless areas tend to show that the hair sensation has no peculiar quality, but may be due entirely to the deformation of the skin surface, in the absence of hair follicles. In general the artificial 'hairs' seemed to give a less intense sensation; but there was no qualitative difference. In such work the method of asking the subject to discriminate between the real and the artificial stimulus gives convincing results; it is capable of extension to other types of skin sensation.

## *Conclusions*

The hair as a sensory apparatus is like a willow shoot deeply rooted in loose sand. When the hair-shaft is moved the movement is greatest at the surface; pressure is exerted on the neural rings, etc., which make up the upper innervation of the follicle; often there is compression of the rings between the hair follicle and the surface; at the same time *the surface of the skin at the point where the hair emerges is freely moved.*

It is practically certain that the lower innervation of the papilla of the hair is not a sensory organ. The sensation of the hair, then, results from 1) the compression of the upper innervation (b in fig. 3) and 2) from the deformation of the skin surface at the point of emergence (a in Fig. 3). There is no qualitative difference between the two factors.

When pressure is applied to the 'pressure spot,' the resulting stimulus is complex: 1) there is stimulation of the skin surface at the point (a in Fig. 3), 2) compression of the upper innervation of the follicle (b in Fig. 3), and 3) deformation of the skin at the point of emergence by the pressure transmitted by the hair-shaft (a in Fig. 3).

Tests of denuded areas and of scars show that hair follicles are not essential to any variety of pressure or touch sensation, and that the threshold for pressure is but slightly lowered by the removal of the follicles.

In the hairy areas the end-organs for touch, then, are not confined to the hair follicles, but are found throughout the skin surface, and they are regenerated in epithelial scar tissue. The innervation of the hair papilla is not a sensory end-organ. The hair follicle is not furnished with endings for pain.

# MECHANISM OF THE DIFFERENT TYPES OF MOVEMENT

R. H. STETSON

WITH A PRELIMINARY REPORT OF EXPERIMENTAL DATA

JAMES A. McDILL

The fundamental thing in the process called a movement is the muscular contractions; the extent of actual change of position of the member involved depends on conditions. The movement of the member is the usual purpose of muscular action and movement is often taken as the index of muscular action. In rapid, repeated movements it is probable that change of position of the moving member is of importance in the cycle of neuro-muscular changes on which innervation and coördination depend.

In the action of muscles against immovable or slowly moving resistance the individual muscular impulses are difficult to detect and the nature of the reaction is obscured. In the following discussion such actions are not considered. Movements are defined as reactions in which the contraction of the muscles affect the position of the moving member.

### *Classification of Movements*

1. Fixation; in which groups of opposing muscles are contracted against each other. This is the movement of holding still.
2. The slow movement; in which the groups of opposing muscles are contracted but with uneven tension so that change of position of the moving member results. Often called the "controlled movement" because it can be changed at any point in its course.
3. The rapid movement; which cannot be changed at every point in its course but is usually determined entirely before the movement begins. The movement is a matter

of preliminary set, "Einstellung." Two kinds of rapid movement may be distinguished.

A. Movements in which there is a tension in all the opposing muscle groups throughout the movement.

B. Movements in which the contraction of the positive muscle group relaxes long before the end of the movement; the termination of the movement may be due to the contraction of the antagonistic muscles. This kind of movement was named by Richer "ballistic" because the moving member is actually free from muscular tension in the middle of its course and is carried on by its own momentum.

1. Fixation—The Movement of Holding Still.

All the various fixations of joints and members are of this type. Every ordinary distal movement requires a proximal fixation. Postures are of course movements of holding still. Recent work has shown that "muscle tonus" is merely a posture reflex.[1]

A record of the movement of holding still, as of a hand holding stylus or of a finger tipped with writing point, shows that the member is only approximately at rest. The member describes to-and-fro movements about a center. In a common form of the "steadiness test," a stylus is held in holes of varying diameter and the extreme amplitude of the movement determined. For the purpose of comparing and relating types of movement the number of tremors per second is more important than the amplitude. Luciani notes such a definite tremor in case of an outstretched arm.[2] He quotes Richet as giving 10-11 per sec. as the frequency of tremor. F. B. Dresslar studying rapid voluntary movement determined the tremor of the members involved:

Forearm—12.2. per sec.

Wrist, lateral—12.9 per sec.[3]

[1] Sherrington, C. S. Postural activity of muscles and nerves, Brain, *38*, '15, 191. Langelaan, J. W. On muscle tonus, *ibid.*, 235.

[2] Human Physiology ('13) '15, 563.

[3] Some influences which affect the rapidity of voluntary movements, Am. J. Psy. *4*, '91-'92, 514.

It has been assumed that this muscular tremor denotes the rate of synaptic reflex discharge through the motor nerve into muscles. Luciani quotes Horseley and Schäfer,[4] and Sherrington quotes Schäfer;[5] but more recent studies have made it clear that this unit of muscular movement cannot be referred directly to the frequency of impulses in the motor nerve.[6] The reflex motor nerve frequency is given as 50-150 per sec. And it is noted that there are 3-4 neural impulses for each muscle twitch. It is true that tetanus occurs in skeletal muscle if the frequency of the sensory stimuli is greater than 15 per sec.,[7] but this does not mean that there is a single motor impulse for each sensory stimulus; instead there is a train of motor impulses for each sensory stimulus.[8]

For some time the attention of investigators was centered on this frequency of c.50 per sec. as indicated by the action currents from the muscles. Recently De Meyer has published a series of studies in which he points out that the curves of previous investigators show other and lower frequencies superimposed on the c.50 per sec. rate. Laboratory work shows that there are currents of deformation of muscle due to any lengthening or shortening of muscle, as well as action currents due presumably to chemical changes in the myofibrillae.[9] The lower frequencies noted by De Meyer are of the order of 10 per sec., and are probably to be identified with tremor.

One might be inclined to say that the chemical changes which register themselves in action currents did not appear as actual

[4] *Ibid.*, 562.

[5] Integ. Act. N. Sys. 206.

[6] Beritoff, J. S. Zschr. f. Biol., *64*, '14; 161; and Piper, Arch. f. Anant. u. Phys., Ph. Abt., '14, 345; (Cited Gen. Rev., Psy. Bull., '16.)

[7] Starling, Prins. of Hum. Physiol., '12, 228.

[8] Beritoff, Ub. d. Erregungsrhythmik d. Skelettenmuskeln b. refl. Innervation, Zschr. f. Biol. *64*, '14, 161. Lucas, Keith, The Conduction of the Nerve Impulse, Lond. '17.

[9] De Meyer, J. D., Des differents sources de courants électriques des systèmes musculaires, p. 44. Sur les courants de déformation des muscles, p. 64. De la dualité d'origine des courants électriques produits par les muscles striés, p. 173. Arch. internat. de physiol. *16*, '21.

movements of the gross muscle, but merely as phenomena within the fiber. But the work of Hill using a direct record from the moving muscle (air tambour, hot wire to string galvanometer) shows that the rate of c.50 per sec. does appear in the movement of the member. It is difficult to imagine how the multitude of minute neuro-muscular processes can be kept in phase so that this rate is impressed on the mass movement, but the records are very clear. However, a second and lower frequency to which Hill does not call attention is very obvious in his published curves. There is too little material to make a very definite calculation, but apparently this lower frequency is c.10 per sec. and corresponds to the slower frequencies emphasized by De Meyer.[10]

Although nothing can be said as to the nature of this tremor frequency there is good reason for assuming that it marks the period of a unit of movement. Starling has shown that the duration of the cycle of the muscle twitch at the ordinary temperature is c.100-180 sig., 6-10 per sec.[11] In fibrillation of the muscle, a study of the continuous series of contractions shows that the rate of the fibrillar cycle is 10-20 per sec.[12] This unit movement appears in the various combinations which make up the types of movements.

## 2. Slow or "Controlled" Movements.

If the movement of holding still be extended in a given direction, it is evident that the beginning of the extension will be a tremor. If the attempt be to make a very small movement, the extent of a tremor will determine the extent of the movement which must consist of two or more tremors. The ability to make movements more and more minute is not limited by sensory methods of control, but by this fundamental tremor element of muscular action.[13]

[10] Hill, A. V., Tetanic nature of the voluntary contraction in man, J. Phys., *55*, '21, xiv.

[11] *Ibid.*

[12] Stevens, H. C., The cause of muscular atrophy following nerve sec. J. Am. Med. Ass. *60*, '18, 385.

[13] Work of L. T. Anderegg and J. Merle Scott in the Oberlin laboratory

When the movement is not so minute as to be limited by a few tremor lengths it is still apparent that the tremor impulses are present. Luciani states that a record of slow voluntary contraction of any muscle (e.g. the opponens of the thumb) shows undulations which are fairly regular in frequency—though irregular in amplitude—c.10-12 per sec. He quotes Griffiths' statement that an increase in frequency to 15-18 per sec. results when a load is applied to the moving member.[14]

Like the movement of holding still, a slow movement is due to the contraction of opposing muscles. In its simplest form the progress of the movement results from tremor increments in one of the muscle groups. Since the movement elements occur as frequently as 10 per sec. and since the increment is very slight, developing little or no momentum in the moving member, the movement can be changed at any movement element (tremor). No neuro-muscular provision is made in advance for the control of the movement. The slow movement is probably due to a series of slight increases in the algebraic sum of the number of muscle fibers contracting in the positive muscle group as against the number of fibers contracting in the antagonistic muscle group. This type of slow movement has been described and the essential difference in its mechanism from that of the fast movement has been discussed by Richer.[15] The sharp difference in type between fast and slow movements of the eyeball has been repeatedly noted.[16]

3. FAST MOVEMENTS.

As a slow movement is increased in speed, the movement elements will be stretched out; their frequency remains the same but there will be fewer undulations per unit of length. For a

shows that magnification of the visual field does not improve the delicacy of minute movement. Quite as minute movements can be made without the eyes as with normal vision or with magnification.

[14] *Ibid.*, 562.

[15] D'Arsonval et autres, Traité de physique biologique, '01, Tome I, 156,

[16] Gertz, H., Üb. d. gleitende (langsame) Augenbewegung, Zschr. f. Ps. u. Ph. d. S. Abt. 2, (1), *49*, '14, 15. Dodge, R., Psy. Rev. *7*, '00, 454. Dodge, R., and Cline, T. S., Psy. Rev. *8*, '01, 155.

path of given length a speed should be possible at which the entire movement shall be a single stretched-out movement element. The movement will now be a smooth curve, a single undulation. The control of the movement will depend on a single impulse in the one group of muscles which starts the movement and on the intervention of a second impulse in the antagonistic muscle group which stops the movement (if it is a free movement without obstacle, like beating a baton in the air, writing, rapid shifting of the eyeball, etc.)

It is now apparent that such a rapid movement cannot be subject to control after it is once started; movement elements occuring at the rate of 10 per sec. are the units; at most then movements can be modified not oftener than ten times in a second. A movement occurring at the rate of 10 per sec. and consisting therefore of a single movement element and terminated by the following movement element must be the result of an adjustment preceding the entire movement. The movement at maximum rapidity is controlled by a preliminary "set," "Einstellung."

A. *Fast Movement under Tension.*

If the fast movement be considered as developed from the position of fixation of the moving member the movement may be due to a sudden excess contraction of one of the groups of muscles making up the complex of muscle groups involved in holding still, followed by an excess contraction in the antagonistic muscle group which stops the movement. A movement of translation is thus superimposed on the fixation, and the movement occurs under tension. Not only are the muscles contracted which have to do with guiding the movement (Du Bois Reymond's pseudantagonistic synergie) but the positive muscle group and the antagonistic muscle group also maintain a tension against each other throughout the movement.

B. *The Ballistic Movement.*

The ballistic movement is a common form of the fast movement; it consists of a single unit contraction of the positive muscle

group followed by a unit contraction of the antagonistic muscle group. The moving member is not under tension from both muscle groups; the movement of translation is not superimposed on a fixation. Instead, a single tremor impulse of the positive muscle group starts the movement; the contraction of this impulse dies out before the second tremor impulse of the antagonistic muscle group appears to check the movement. There is therefore a median part of the movement in which the moving member swings free carried by its own momentum. There may be fixation of a joint and there is the guiding tension of muscle groups which determine the path of the movement, but there is no opposing tension to the flight of the moving member.[17]

In a to-and-fro movement at maximum speed the unit contraction which checks the one movement becomes the driving impulse for the reverse movement, relaxing before the positive unit contraction reappears to check the reverse movement and start the moving member on its second flight. Such a to-and-fro movement ought to approach very close to the tremor rate as indeed it does. F. B. Dresslar's observation that the maximum rate of tapping is c.10.5 per sec., while the tremor rate for forearm and wrist is 12.2 and 12.9 respectively should have been taken as evidence that the two values are closely related and not that they are due to distinct processes.[18]

T. G. Brown makes the fundamental unitary mechanism to consist of the efferent neurones of two antagonistic muscles.[19] It is possible that the maximum rapidity of a repeated movement is limited by the rate at which excitation and inhibition can be developed in two antagonistic muscle groups. If one assumes that inhibition is due to the combination of trains of excitation in pulses in the motor nerves (K. Lucas, Verworn, etc.) it may well be that the overlapping of the series to produce the continuous refractory condition followed by the normal conducting condition has a definite time limit. It is probable that the me-

[17] Richer, P., *loc cit.*

[18] Some influences which affect the rapidity of voluntary movements, Am. J. Psy. *4*, '91-'92, 514

[19] J. Physiol. *48*.

chanical change due to movement is an important factor in the coördination.

The fast movement under tension and the ballistic movement have not always been distinguished. But in many types of skilled movement the distinction is important. In piano playing, in violin playing, and in telegraphy the contrast between the "tight" or "stiff" rapid movement (fast movement under tension) and the "loose" rapid movement (ballistic) has come to be a commonplace. Piano technic has been recognized during the past thirty years on that basis.

At the highest rate of repetition there can still be variation from movement to movement if not during the flight of any single movement. Although the duration is fixed the extent of such movements is subject to wide variation. This has been noted in several movement studies.[20] The ballistic movement is capable of the most delicate adjustment, in extent as in the case of writing and keyboard manipulation, and in force as in case of dynamic shading in violin or piano playing, singing, speech, etc.

Since the duration of the rapid movement is fixed, there can be but two variables, extent and force. This limits somewhat the problem discussed by Morgan and Goerrig.[21]

*Experimental Results.*

Tremors in fixation of finger—movement of holding still.

The right hand was supported on table in comfortable position. A writing point, the point of a sharp needle, was fastened to the

[20] Stetson, R. H., Theory of rhythm and discrete succession, Psy. Rev. *12*, '05, 261. Isserlin, M., Üb. d. ablauf einfacher, willkürlicher Bewegungen, Psy. Arb. *6* (1), 1910-14, 86, who states clearly that the total duration of rapid movements remains the same for a given person no matter what the extent of the movement. Freeman, F. N., Anal. of the writing movement, Psy. Mon. Sup. *17*, '14, No. 4, 1-46, who confirms Binet and Courtier in statement that in case of rapid writing movements the increase of extent of a single movement, or of the writing as a whole, does not mean an increase in duration of the stroke or strokes, but rather increase in speed; the time of rapid writing is independent of its size.

[21] Morgan, J. B., The speed and accuracy of motor adjustments, J. Xp. Psy. *2*, '17, 225. Goerrig, M. A., Einfluss d. Zeitdauer auf d. Grossenschätzung v. Armbewegung, Arch. f. d. ges. Psy. *36*, '17, 293.

nail of the index finger. The other fingers and thumb rested on the table while this index finger was held extended with the writing point in contact with a smoked glass slide perpendicular to the table, so that the finger movements were recorded in the vertical plane. A Jacquet chronograph marking fifths of sec. on the slide afforded a record of time intervals. The glass slide was drawn in a groove by a thread winding on a kymograph drum running at rather slow speed.

The records were measured under a Zeiss binocular microscope. To avoid errors each change in direction was counted and the result divided by two. The slides were labeled, the smoked record mounted with cover glass and balsam in the usual manner.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Subject W | Record of | 9 | seconds; average per sec. | 6.8 | Mean variation | .8 |
| | | 13 | | 8.2 | | 1. |
| | | 7 | | 8.2 | | 1.1 |
| | | 8 | | 8.1 | | 1.1 |
| | | 8 | | 7.8 | | 1.3 |
| | | 10 | | 7.7 | | .7 |
| | | 10 | | 7.7 | | .9 |
| | | 7 | | 7.3 | | .8 |
| | | 8 | | 6.5 | | .9 |
| | | 11 | | 7.3 | | .5 |
| | | 4 | | 7. | | .9 |
| Subject A | | 5 | | 7.4 | | .9 |
| Subject N | | 7 | | 8. | | 1.5 |
| Subject D | | 5 | | 6.9 | | .3 |

These records show a fairly definite frequency which varies somewhat from sitting to sitting and from subject to subject. The mode is c.7.5 per sec. which is somewhat lower than other results but not significantly so.

Tremor-undulations in various types of movement at various speeds:

Short, straight lines of 3-4 mm. were drawn with the ordinary writing movement of fingers and hand at speeds varying from 14-160 per minute.

Longer lines of 440 mm. were drawn with pencil by movements of the forearm and upper arm, at speeds varying from 14-160 per minute.

The short lines of 3-4 mm. were drawn on smoked glass slides, the click of a metronome indicating the beginning and end of the parallel lines. There are several sources of possible variation: the speed of the movement may vary, and the movement may not occur within the indicated time interval. As the movements are repeated and rhythmic, these variations are limited and tend to compensate. The lines were measured under the microscope and averaged in groups of 30.

*Subject A*

| | | | | |
|---|---|---|---|---|
| 30 lines, | 14 lines per min. | 4.28 sec. per stroke, | 10.1 undulations per sec. | m.v. 1.1 |
| 30 | 22 | 2.72 | 12.2 | 2.4 |
| 30 | 48 | 1.25 | 15.3 | 1.1 |
| 30 | 60 | 1. | 12.3 | 1.6 |
| 30 | 70 | .86 | 11.7 | 1.4 |
| 30 | 80 | .75 | 11.2 | 1.4 |
| 30 | 90 | .67 | 11.4 | 1.7 |
| 30 | 100 | .60 | 10.5 | 1.4 |
| 30 | 110 | .54 | 9.8 | 2. |
| 30 | 120 | .50 | 9.8 | 1.8 |
| 30 | 130 | .46 | 10.6 | 2.1 |
| 30 | 140 | .42 | 11.1 | 2.2 |
| 30 | 150 | .40 | 11.5 | 1.9 |
| 30 | 160 | .37 | 11.3 | 1.8 |

Although there is considerable variation, it is clear that the "undulation" marks some definite frequency which remains fairly constant throughout the series. This tremor undulation indicates some fairly constant element in the movement; it is possible that the record is of impulses in the "pseudantagonistic" muscle groups rather than in the driving muscles; but slow movements like that of closing the fingers show that driving muscles also have the same pulses. Although these movements are approximately of the same length, the slowest movement has an average of 43 of these elements, and the fastest movement has an average of 4.

The longer lines of 440 mm. were drawn between limiting perpendicular lines on smooth cardboard sheets with a hard pencil; the beginning and the end of the line was indicated by metronome click. In studying the lines, the sheets were placed on inclined plane to bring one end nearer the eye; by "squinting" down the fore-shortened line the undulations could be counted.

*Subject P*

| | | | |
|---|---|---|---|
| 30 lines. | 8.4 lines per min. | 4.4 undulations per sec. | M.v. .9 |
| 30 | 14 | 5.6 | .8 |
| 30 | 22 | 6. | |
| 30 | 42 | 6.9 | |
| 30 | 48 | 7.9 | 2. |
| 30 | 60 | 7.6 | 1.7 |
| 30 | 70 | 8.2 | |
| 30 | 80 | 7.7 | |
| 30 | 90 | 8. | |
| 30 | 100 | 8.2 | |
| 30 | 110 | 8.6 | |
| 30 | 120 | 8.3 | |
| 30 | 130 | 7.7 | |
| 30 | 140 | 8.1 | |
| 30 | 150 | 8.1 | |
| 30 | 160 | 8.1 | 2.2 |

There is more variation from rate to rate than in the record of short lines; the mean variation at a given speed is about the same as for the shorter lines. It is to be expected that the frequency of the tremor-undulation would be somewhat slower when larger muscles are involved; it is a familiar fact that the maximum rate of larger muscles is slower.

Certain difficulties are involved in starting and stopping at a limiting line when drawing lines by the above method. To avoid these difficulties a series was made in which the pencil was in motion when passing the limiting lines; a flying start and a flying

*Subject M.*

| | | | |
|---|---|---|---|
| 30 lines. | 14 lines per min. | 4.2 undulations per sec. | M.v. 1.1 |
| 30 | 22 | 5.8 | |
| 30 | 48 | 9.5 | |
| 30 | 60 | 6. | |
| 30 | 70 | 6.2 | |
| 30 | 80 | 6.8 | |
| 30 | 90 | 6.8 | |
| 30 | 100 | 7.8 | |
| 30 | 110 | 6.9 | |
| 30 | 120 | 6.2 | |
| 30 | 130 | 6.8 | |
| 30 | 140 | 7.3 | |
| 30 | 150 | 6.8 | |
| 30 | 160 | 7.2 | 2.4 |

stop. A possible source of error may lie in the varying accuracy with which the subject drew the pencil across the limiting lines on the click of the metronome. The length of line measured was 300 mm.; the number of undulations was counted as before.

These records of tremor frequencies agree very well with material previously published. But there are too few subjects for the various types of movement. There are records from only three for the study of tremor in fixation, records from only two for the study of the longer movements, and records from only one subject for the study of small movements. The results although insufficient are fairly consistent and indicate a single unit frequency in all sorts of movements at varying speeds. This unit frequency is very close to the maximum frequency of voluntary movement for the given groups of muscles.

*The Termination of Skilled Movements.*

The purpose of many skilled movements is achieved at the end of the stroke; there the work is performed, the blow struck. Although the entire path of the movement is important in the case of a few movements like writing, drawing, use of surface-working tools and some phases of musical conducting, yet for such movements there is always a definite termination.

The terminations of movements may be classed as follows:

1. The moving member swings loose about joint; movement is terminated by ligaments and passive muscles.
2. The moving member is arrested by the antagonistic muscle group.
3. The moving member is arrested by an obstacle, a "block."

1. The form of movement in which the moving member is brought to a stop by the ligaments and passive muscles is rather unusual; the movement of the hand in plucking the balalaika and the swing in golf are illustrations. In pitching a baseball the muscles are brought into play enough to hold the arm in position after the delivery but the termination of the movement is due primarily to the passive tissues about the shoulder joint.

2. The moving member is brought to a stop by the antago-

nistic muscle group in the "free" or self-limiting movement. The movements are often executed in the air without any resistance as are most gestures and the movements of the orchestra conductor. All the movements of the eyeball are self-limiting. Many calisthenic and athletic exercises involve such movements either untrammelled or against a slight resistance. Auxiliary arm movements in walking, running, and dancing are quite free. Club swinging, and wand drills involve movements against a slight resistance. In rowing and swimming the resistance is more pronounced but the end of the movement is determined by the opposing muscles. The movements of writing and drawing meet a slight resistance; surface working tools involve varying degrees of resistance. In speech repeated vowels and liquids require self-limiting movements of large muscles. Violin bowing and the manipulation of the slide trombone involve self-limiting movements against a slight resistance. In plucking the harp or guitar string the movement creates a sharp, elastic resistance, releases it and passes to a limit fixed by the muscles themselves.

Only a few self-limiting movements are terminated by the contraction of the antagonistic muscle group acting directly against the contraction of the positive muscle group. Slow movements of the "controlled type," are stopped by the increased tension of the antagonistic muscles and there is little momentum to be taken up.

Wherever the movement must be delicately gauged as to point in time, degree of force, or exact form of movement a fast, "ballistic" movement is used; the "back stroke" and the preparation for the movement may be slow and there may be long pauses between "beat strokes," but the stroke itself is a fast movement. If the ballistic movement comes to rest at its termination, there is a fresh contraction of the positive muscle group with other muscles involved in maintaining the position of the member. Repeated movements at maximum speed show no period of standstill; the end of the movement presents a remarkably sharp angle. The flight of the moving member initiated by the positive muscle impulse meets the gradually increasing tension of the antagonistic muscle group which reverses it. The

change of direction is almost instantaneous like the rebound of an ivory ball from a hard surface, or of a light weight with an elastic spring. Rieger observed this rebound and referred it to the positive muscle group.[22] Isserlin is right in objecting to this interpretation but wrong in assuming that a pause must intervene. It is quite true that in repeated fast movements there is a definite "relaxation" process in the sense that the momentum of the moving member must be taken up and the contraction of the antagonistic muscle group developed; but in the swifter ballistic movements the moving member is descending and rising without pause during this "relaxation period."

3. In a very large group of skilled movements the moving member meets an obstacle, a block which stops the movement without further muscular activity; whereupon in most cases the antagonistic muscles presently contract and return the moving member to the initial position. At medium speeds the block may be said to truncate a complete movement which would swing to a later termination coming to a stop with the contraction of the antagonistic muscle group; instead there is a period of rest at the block during which the antagonistic contraction takes place. As a repeated movement to a block approaches maximum speed, the pause grows less and less; finally the block becomes a mere limit, the angle of reverse becomes sharp and the form of the movement has become of the self-limiting type. Slow movements may rest at the block and perhaps exert some pressure on the block; but for the highest speed there must be no pressure whatever on the block.

Many of the skilled movements of musical performance are against a block; piano and organ playing, fingering of strings and wood wind and the brass. In piano playing rapid octaves if played properly will actually exert very little pressure on the pad beneath the keys. In typing and adding machine work also keys are pressed down through slight resistance to a definite block. Sometimes the blow is delivered to a resisting surface as in the various movements of locomotion and in many of the consonant

22 Üb. Muskelzustände, Zschr. f. Ps. un. d. S. *31*, l. *32*, 377.

strokes of speech. Sometimes the external resistance is elastic although powerful enough to check, and even to reverse the movement; leaping from a spring board, dancing on a tight rope, and beating the various drums are terminations of this type.

Blocked movements, movements with and without resistance, and self-limiting movements frequently occur side by side and are nicely organized as in the work of an orchestra. The delicacy of expression and celerity possible in methods of execution as different as those of the piano, violin, harp, and voice show that there may be a remarkable control of any of these forms of termination of the skilled movement.

*Experimental Results.*

It is easy to show that the nature of a movement is not affected by the fact that it meets increased tension during a part of its extent, nor by the fact that it comes up against a complete block. If the increased tension is small as compared with the weight of the moving member, there is no change in the curve representing the movement and it sweeps to the end without perceptible change. The muscular contractions for stopping a self-limiting movement and for returning the member if the movement is repeated are adjusted to the external tension; the form of the movement is in nowise affected.

Figure 1 shows a movement of the hand and arm making an excursion of 150-250 mm. During the lower 50 mm. of the free excursion the hand strikes a platform of small mass suspended by elastic bands which give a tension increasing to 150 g.

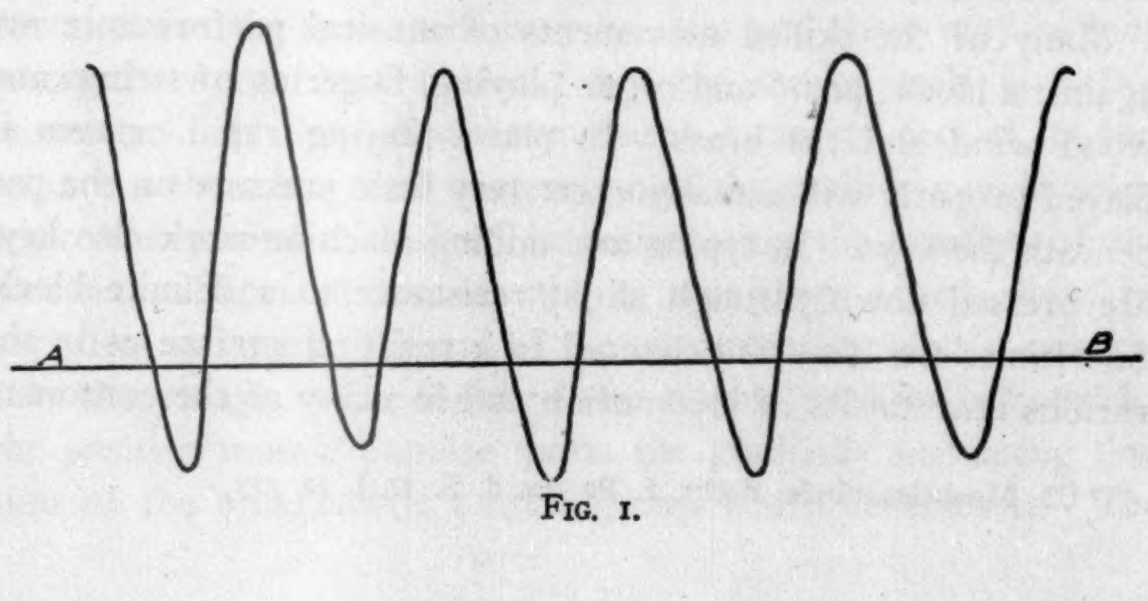



FIG. 1.

at end of stroke. There is no indication of a change in the movement when the hand comes in contact with the platform.

Subject blindfolded. Platform raised and lowered rapidly through 60-70 mm. Tension 350 g. Points at which platform is raised-and-lowered are marked "*".

| Duration of platform movement, sec. | Extent of platform movement, mm. |
|---|---|
| .27 | 46 |
| .27 | 52* |
| .22 | 41 |
| .22 | 41 |
| .26 | 51* |
| .22 | 41 |
| .20 | 36 |
| .23 | 47 |
| .23 | 50* |
| .25 | 46 |
| .21 | 36 |
| .19 | 41 |
| .19 | 44 |
| .19 | 41 |
| .20 | 50* |
| .20 | 42 |
| .18 | 34 |
| .19 | 43 |
| .23 | 49 |
| .24 | 53* |
| .21 | 40 |
| .21 | 36 |
| .21 | 40 |
| .23 | 56* |
| .22 | 43 |
| .21 | 38 |
| .24 | 50 |
| .24 | 50* |
| .17 | 27 |
| .22 | 38 |
| .27 | 53 |
| .28 | 48* |
| .18 | 28 |
| .26 | 46 |
| .30 | 65* |
| .25 | 38 |
| .23 | 29 |
| .26 | 37 |

Here the change of level of the platform has been made rapidly enough so that there is no readjustment. The movement dips into the platform tension and goes deeper when the platform is

| Duration of platform movement, sec. | Extent of platform movement |
|---|---|
| .31 | 55 |
| .29 | 51* |
| .27 | 42 |
| .27 | 46 |
| .26 | 40 |
| .26 | 40 |
| .26 | 35 |
| .26 | 31 |
| .31 | 44 |
| .37 | 58* |
| .36 | 46 |
| .30 | 47 |
| .22 | 32 |
| .18 | 15 |
| .20 | 31 |
| .27 | 43 |
| .25 | 48 |
| .28 | 55* |
| .26 | 53 |
| .27 | 51 |
| .22 | 45 |
| .30 | 56 |
| .27 | 55 |
| .27 | 51* |
| .27 | 55 |
| .24 | 46 |
| .23 | 49 |
| .24 | 45 |
| | Change of platform level 110 mm. |
| .23 | 40 |
| .22 | 40 |
| .24 | 43 |
| .24 | 45 |
| .23 | 43 |
| .23 | 40 |
| .25 | 51* |
| .22 | 42 |
| .23 | 39 |
| .19 | 36 |
| .22 | 41 |
| .25 | 43 |
| .23 | 37 |

raised and comes back immediately to the original movement form when the platform is lowered to the normal position. The duration and extent records show that roughly the same speed is maintained throughout.

Subject blindfolded, makes free strokes which carry down the elastically suspended platform. The level of the platform is raised and lowered slowly; the points where platform is at maximum height are marked "*". Change of level 60-70 mm. Tension 350 g.

Where the changes of level are made gradually the tendency to readjust is apparent; the movement is adjusted by the preceding movement sensations, not by the sensations from the movement occurring. There are many illustrations of this adjustment in ordinary life: adjusting to the dimensions of the steps as one climbs a staircase; adjusting to the touch of a strange piano or typewriter: adjusting to a novel height of heel in walking, etc. Some eighteen series of records of this sort were taken at various speeds of ballistic movement; they all show the same facts as those given above. The records are from but a single subject, however, and need corroboration.

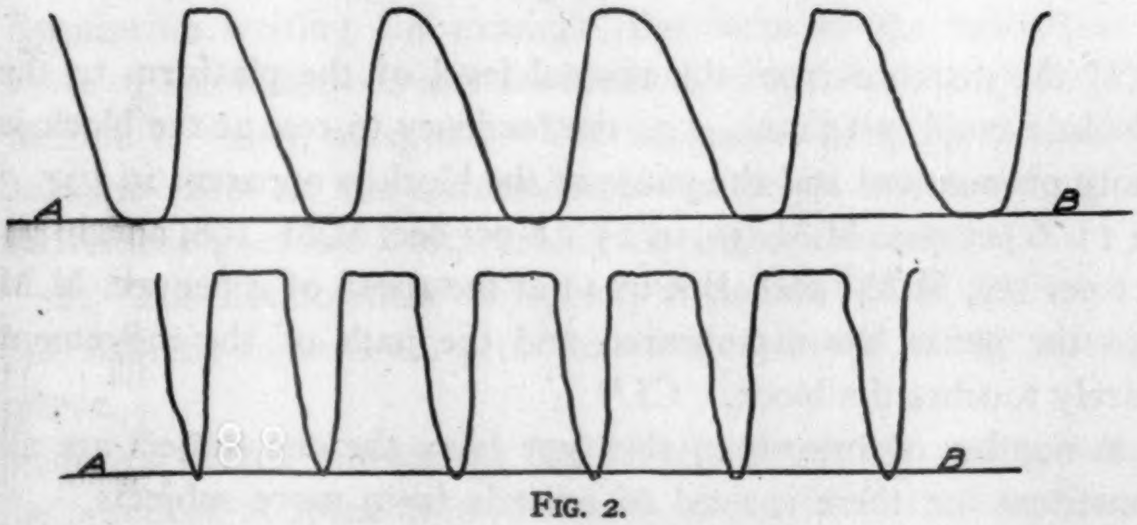



FIG. 2.

When the movement plays against a block, a very common form of rapid stroke, if the movement is slow, the member rests at the block and the curve looks precisely as if a longer self-limiting movement had been truncated by the block. Series 1) if completed would have been 60-70 mm. in length. The momen-

tum and possibly some contraction of flexor muscles is expended at this block level and the extensor contraction which is to raise the arm and hand develops during this period of rest.

If the speed of the movement to the block is increased to 1.4 per sec. the form of the movement changes and the pointed end of the movement occurs at the block, Series 2); there is no longer a period of rest at the block. Very little energy is expended on the block; the momentum developed in the moving member is quickly neutralized by the extensor muscles and the moving member is thrown lightly back from the block level.

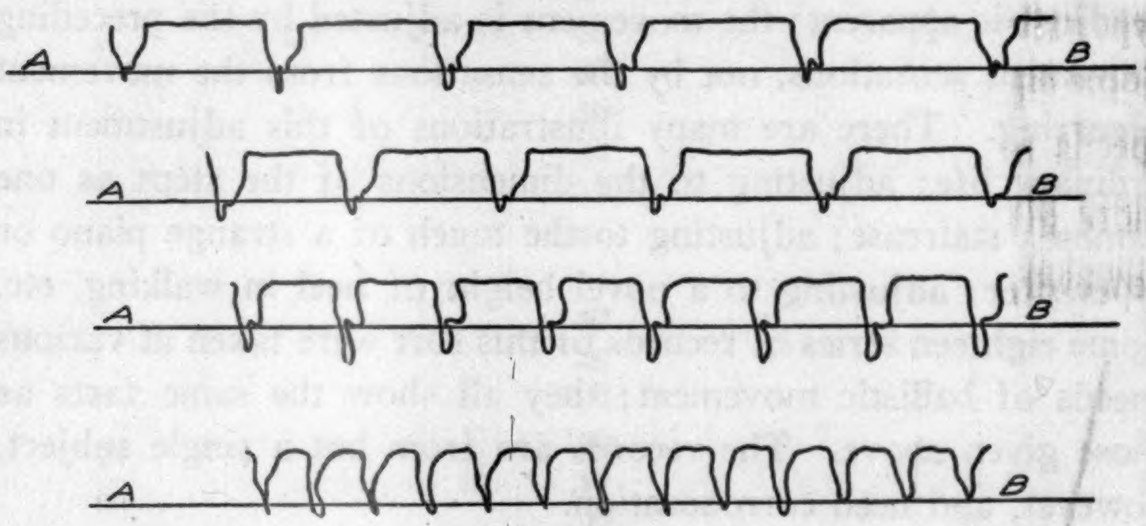



FIG. 3.

If the distance from the normal level of the platform to the block is small, 5-15 mm., e.g., the tendency to rest at the block is more pronounced and the pause at the block is apparent in Fig. 3 in 1) .6 per sec., M.M 36, in 2) 1.8 per sec. M.M 108, and in 3) 2.1 per sec. M.M 126. But in 4) at the speed of 4 per sec. M.M 240 the pause has disappeared and the path of the movement barely touches the block. Cf.[23]

A number of records of this type from the one subject are all consistent but there is need of records from more subjects.

*Bearing on the Type of Movement on the Process of Learning*

1. The "form" of the movement:

Wherever rapid and repeated movements are important as in musical technic, use of keyboard machines, telegraphy, writing,

[23] Mot. Theory of Rh. and Discrete Suc. Psy. Mon. Sup. *12*, '05, 263.

and shorthand, the type of movement has been recognized as very important. Keyboard work has been completely reorganized on the basis of the "loose" movement which is simply a carefully maintained ballistic movement of finger, hand, and forearm with the use of weight of momentum as far as possible. Telegraphic keys have been modified and the technic emphasized because both speed and freedom from occupational neurosis depend on obtaining the ballistic form. In writing it happens that a remarkable piece of early work was done in the development of the ballistic technic. Spencer not only developed remarkably good cursive forms of the written letter, but he also achieved a technic of the writing movement which gave great speed and endurance with beauty of form. There are careful directions for the "muscular movement," in which the forearm slides freely and ballistically about on the mass of flexor muscles and tight, cramping movements of the finger and hand are avoided. Chinese and Japanese brush writing and drawing have also achieved the fast, free stroke. The line of Japanese painting is a free hand and free arm drawing with the swift certainty of the skilled ballistic movement. The bad line in drawing is the result of "controlled" movements. In many of these skilled movements, piano playing, telegraphy, Spencerian writing for example, the form of the movement is more or less conscious and the method of training for getting the technic is fairly adequate. But in many skilled processes the ballistic form of the movement is the result of chance or the movement goes on hampered by opposing tensions.

2. The development of speed; transition from the slow to the ballistic movement; problem of the plateau of the learning curve.

A few skilled movements like diving or serving at tennis must be practiced at speed from the start, but most of the complicated skilled movements are begun slowly and gradually increased in speed. Mistakes in the precise path of the movement are usually counted lapses in "accuracy." These are kept to a minimum and constantly corrected while the movement is repeated at higher and higher speed. This is the great feature of the process called

training or "development of skill." It is usually assumed that the movement is being stereotyped, ground in by repetition, and that the increase of speed is merely a matter of gradually increasing the tempo while the movement remains the same. First get the path of the movement accurately and then gradually speed up until you reach the normal tempo. On the assumption that it is one and the same movement process at the different speeds it has always been something of a puzzle that the learning curve fails to show a regular increase in speed. Instead of a gradual and regular increase, the curve shows rather rapid gains at points with long periods of practice between during which there is no apparent gain at all. There are various explanations: periods of assimilation in which recent gains are being consolidated; compensation between improvement and fatigue, etc. The fundamental fact is that the movement itself changes with the increase in speed; it is not the same movement throughout training. Beginning as a slow process composed of many movement elements and with frequent pauses, the increasing speed means that fewer movement elements must take the place of the many. The *path* of the movement has not changed but a process which included twenty movements, and might be stopped at twenty different places and may have paused at many of them, is now reduced to fifteen, to seven, to three. In reality passing from slow to rapid is a matter of substituting a single movement for several movements over the same path. Nothing else can happen; if about ten movement elements per second is the maximum, a given movement beginning with ten movement elements must be reduced to less than ten movement elements when the speed exceeds one per second. If the given movement takes place at the rate of two per second the original ten movement elements must be reduced to at most five. When the beginner prints a character at the typewriter he first puts his finger on the key, and then presses it down; later the placing and striking must become one stroke. In many cases different groups of muscles are employed for the slow and the rapid movements; the movements are different in every sense, they consist of different numbers of grouped movement elements

executed by different muscle groups. And this fact must have an important influence on the learning curve. When the "form" of the movement is stable, when the number and grouping of the movement elements is no longer changing, the increase in speed is very slow indeed but is gradual—as at the end of training when the subject comes very slowly to his maximum efficiency. It is perhaps due to gradual nutrition changes ("development" of muscles) and to the refinement of the cues and adjustments which direct the movement. But during a large part of the obvious and relatively rapid improvement, the "form" of the movement, the actual movement-process is subject to change. When a new and more condensed group of movement elements is substituted for the more detailed and segmented group there is a very rapid increase in speed. But these new "forms" of movement, these new combinations of the individual units are blundered into. During the plateau the subject is repeating the movement verbatim until chance gives a better way and he falls into a better "form." "Plunging" at the expense of mistakes has its advantages for thereby the subject comes to new and more rapid "forms" for covering the same movement path. The advantage of ensemble playing for the beginner in music is that it forces him to try things at a speed which compels new combinations, with approximate accuracy in the main movements at least. Mere repetition does not constitute fruitful practice; changes in the type of movement used are essential.

### *Summary*

Movements may be classed as 1. movement of holding still —fixation, 2. slow movement, 3. fast movements, A. with tension, B. Ballistic. The difference between these classes is due to the number of movement elements in each type of movement. The movement elements are equivalent to the tremor undulations. In fixation a number of muscle groups contract against each other and the tremor is the only change of position. In the slow movement there are a large number of movement elements per unit of length and the movement can apparently be changed at any

point in its course; it is "controlled." In the fast movement there are few elements, only a few changes are possible; at the maximum rate when each stroke consists of but one element, no change during the course of the movement is possible. In the fast movement under tension the movement of translation is superimposed on a movement of fixation. In the ballistic movement there is a minimum muscle contraction during the flight of the movement. A single impulse of the positive muscle group starts a very rapid movement; during the earlier course of the movement this impulse ceases and the moving member swings free to the termination of the movement. Such a ballistic movement will have a duration independent of the extent of the stroke; long or short, the movement can be repeated at a maximum rate which approaches the tremor frequency of the groups of muscles involved.

There are three common forms for the termination of a movement: 1. the moving member swings loose and is arrested by ligaments and passive muscles, 2. the moving member is arrested by the contraction of the antagonistic muscle group, 3. the moving member is arrested by an obstacle. The first form is less usual; the second is the common type or "free" or self-limiting movement; the third is very common in all sorts of rapid manipulation of mechanical apparatus. When the movement terminating at an obstacle occurs at maximum speed it tends to become self-limiting.

In training the type of the movement changes from slow to ballistic although the path of the movement does not change. Plateaux in the learning curve are due to periods in which the movement is repeated without change of type and therefore at the same speed. Devices in training are important which lead to the development of new "forms" of the movement.

# MEASUREMENTS OF RHYTHMIC UNIT-GROUPS AT DIFFERENT TEMPOS

R. H. Stetson and T. E. Tuthill

The fundamental groups of a rhythmic series consist of accented and unaccented beats. In musical notation it has been customary to give these beats a strictly quantitative expression. It is assumed in musical instruction and occasionally in psychological theory that the quantitative temporal relations are an essential factor in the unit-group.

The iamb or "dotted-eighth-sixteenth" figure was chosen as one of the simplest and most obvious unit-groups with a pronounced difference in the length of the elements and a very definite accent. The question was raised: Is the musical iamb actually played in a fixed temporal form as indicated by the musical notation? The commonest form of the iamb was chosen and a half dozen trained musicians were asked to play this rhythm at different tempos; the records were carefully measured. The form that the musicians were asked to play was always a simple phrase:

The rhythms were tapped on a key which gave a clear sound like that of the Vergil clavier with which all the subjects were familiar. The beats were recorded on a carefully controlled kymograph drum. The subjects were all accustomed to ensemble playing, were considered accurate in rhythm, and were all aware that the "accuracy" of their rhythms was to be tested. They did their best to make the form correct as they conceived it.

The following tables show a sample of the actual measurements in one case and of the computed averages and mean variations for the series of readings of the records of each of the six subjects.

Records of doublets and triplets (trochees and dactyls) have been added for comparison.

## TABLE I

*Subject W.*

Iambs

**Readings in tenths of millimeter from kymograph drum.**

| Metronome rate | 50 | | 80 | | 100 | | 120 | |
|---|---|---|---|---|---|---|---|---|
| | 𝅘𝅥𝅯 | 𝅘𝅥𝅮. | 𝅘𝅥𝅯 | 𝅘𝅥𝅮. | 𝅘𝅥𝅯 | 𝅘𝅥𝅮. | 𝅘𝅥𝅯 | 𝅘𝅥𝅮. |
| | 173 | 561 | 315 | 840 | 137 | 410 | 170 | 706 |
| | 168 | 526 | 285 | 755 | 125 | 370 | 167 | 683 |
| | | | 306 | 764 | 132 | 415 | 172 | 682 |
| | 168 | 506 | 292 | 765 | 120 | 405 | 172 | 677 |
| | 175 | 490 | 292 | 700 | 127 | 377 | 170 | 631 |
| | | | 307 | 663 | 120 | 416 | 160 | 630 |
| | 251 | 830 | 278 | 674 | | | 148 | 681 |
| | 262 | 830 | 280 | 666 | 147 | 460 | 158 | 690 |
| | 242 | 796 | 234 | 570 | 148 | 442 | 170 | 665 |
| | | | 240 | 640 | 136 | 477 | 147 | 676 |
| | 213 | 702 | 233 | 617 | 152 | 476 | 145 | 650 |
| | 240 | 762 | 237 | 616 | 170 | 485 | 160 | 668 |
| | 240 | 730 | 230 | 634 | 167 | 475 | 154 | 650 |
| | | | | | 160 | 496 | 152 | 640 |
| | | | 315 | 849 | | | 158 | 650 |
| | | | 313 | 810 | 175 | 450 | 160 | 663 |
| | | | 321 | 807 | 503 | 184 | 170 | 650 |
| | | | | | 182 | 488 | | |
| | | | | | 196 | 503 | | |
| | | | | | 170 | 510 | | |

**Averages; ratio of the short note to the long note:**

| M.M. | 50 | 80 | 100 | 120 |
|---|---|---|---|---|
| Theoretical ratio, assuming that the iamb is a quantitative expression | 250:750 | 250:750 | 250:750 | 250:750 |
| W. | 240:760 mv 30 | 284:716 mv 30 | 252:748 mv 10 | 190:810 mv 10 |

*Subject W*

| M.M. | 40 | | 80 | | 120 | | 160 | | 180 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 180 | 400 | 135 | 400 | 160 | 400 | 145 | 280 | 140 | 235 |
| | 180 | 500 | 170 | 390 | 165 | 400 | 140 | 260 | 130 | 220 |
| | 195 | 510 | 165 | 520 | 170 | 420 | 130 | 290 | 120 | 215 |
| | 180 | 470 | 200 | 500 | 170 | 420 | 135 | 300 | 120 | 215 |
| | | | 190 | 510 | | | | | 145 | 225 |

Averages:

| | 40 | 80 | 120 | 160 | 180 |
|---|---|---|---|---|---|
| Theoret. | 250:750 | 250:750 | 250:750 | 250:750 | 250:750 |
| W. | 275:725 mv 7 | 268:732 mv 27 | 290:710 mv 6 | 323:677 mv 13 | 366:634 mv 22 |

At the slower tempos M.M. 50 and 80 many of the individual figures are far enough from the theoretical ratio so that the difference could easily be detected by the ear. The average values are not far enough from the theoretical ratio so that the difference could be detected by the ear. The average at M.M. 120 is far enough from the theoretical ratio to be at the threshold of discrimination, 40-66 sigma. It is to be noted that at none of the tempos do the values vary about the theoretical ratio as a norm.

In the second series from the subject W. it is to be noted that the forms do not agree with other records from the same subject, save in having the short note in general longer than the theoretical value.

TABLE II

*Subject M*

Averages of readings expressed as ratios

| | | |
|---|---|---|
| M.M. | 40 | 80 |
| M. | 346:654 av. 14 rdgs mv 59 | 312:688 av. 11 rdgs, mv 12. |
| Theoret. | | |
| | 250:750 | 250:750 |
| M.M. | 100 | 120 |
| M. | 294:706 av. 17 rdgs, mv 12 | 267:723 av. 15 rdgs, mv 13 |
| M.M. | 140 | 180 |
| M. | 285:715 av. 14 rdgs, mv 11 | 326:674 av. 20 rdgs, mv 13. |

TABLE III

*Subject D*

Iamb

Averages of readings expressed as ratios

| | | |
|---|---|---|
| M.M. | 40 | 80 |
| D. | 331:669 av. 7 rdgs, mv 16 | 366:634 av. 9 rdgs, mv 15 |
| | 283:717 5 4 | 354:646 8 14 |
| Theoret. | | |
| | 250:750 | 250:750 |
| M.M. | 120 | 160 |
| D. | 315:685 av. 8 rdgs, mv 6 | 316:684 av. 7 rdgs, mv 9 |
| | 335:665 5 | 316:684 7 13 |
| Theoret. | | |
| | 250:750 | 250:750 |

In Table II the individual unit-groups show values at all tempos which could easily be discriminated by the ear from the theoretical ratio. In the case of M.M. 40 and 80 the average of the readings is so unlike the theoretical ratio that the difference would be obvious to the ear. As often, the mean variation shows greater irregularity at the slow tempos.

The divergencies from the theoretical ratio at the lower tempos as shown in Table III are pronounced and would be obvious to the ear.

TABLE IV

*Subject H*

Iamb

Averages of readings expressed as ratios

| | | | | | | |
|---|---|---|---|---|---|---|
| M.M. | 40 | | | 80 | | |
| H. | 400:600 | av. 10 rdgs, | mv 24 | 393:607 | av. 8 rdgs, | mv 8 |
| | 370:630 | 8 | 22 | 373:627 | 10 | 26 |
| | 362:638 | 10 | 4 | 353:647 | 8 | 14 |
| Theoret. | | | | | | |
| | 250:750 | | | 250:750 | | |
| M.M. | 120 | | | 160 | | |
| H. | 364:636 | av. 11 rdgs, | mv 47 | 366:634 | av. 10 rdgs, | mv 26 |
| | 335:665 | 10 | 17 | 330:670 | 6 | 10 |
| | 330:670 | 7 | 16 | 354:646 | 7 | 7 |
| Theoret. | | | | | | |
| | 250:750 | | | 250:750 | | |
| M.M. | 200 | | | | | |
| H. | 354:646 | av. 9 rdgs | 18 | | | |
| | 360:640 | av. 14 rdgs | 14 | | | |
| | 344:656 | av. 7 rdgs | 34 | | | |
| Theoret. | | | | | | |
| | 250:750 | | | | | |

At all tempos in all three records in Table IV, the short note of the unit-group is much longer than the theoretical value, and as a rule is longer than that given by other subjects. In nearly every case the individual unit-group as played could be discriminated by ear from a figure played with the theoretical values.

The type used by the subject is very definite; there is little variation at any tempo.

TABLE V

*Subject P*
Iamb
Averages of readings expressed as ratios

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| M.M. | 40 | | | 80 | | | |
| P. | 325:675 av. | 4 rdgs. mv | 13 | 318:682 av. | 8 rdgs, mv | 9 | |
| | 342:675 | 4 | 10 | 240:760 | 8 | 14 | |
| | 263:737 | 4 | 8 | 251:749 | 5 | 12 | |
| | 348:652 | 5 | 7 | 222:778 | 3 | 0 | |
| Theoret. | | | | | | | |
| | 250:750 | | | 250:750 | | | |
| M.M. | 120 | | | 160 | | | |
| P. | 283:717 av. | 4 rdgs, mv | 0 | 362:638 av. | 4 rdgs, mv | 33 | |
| | 303:697 | 6 | 10 | 299:701 | 6 | 18 | |
| | 308:692 | 5 | 6 | 325:675 | 5 | 30 | |
| | 246:754 | 4 | 0 | 276:724 | 3 | 0 | |
| Theoret. | | | | | | | |
| | 250:750 | | | 250:750 | | | |

The number of readings recorded in Table V is rather small.

TABLE VI

*Subject S*
Iamb
Averages of readings expressed as ratios

| | | |
|---|---|---|
| M.M. | 40 | 80 |
| S. | 262:738 av. 6 rdgs, mv 18 | 352:648 av. 11 rdgs, mv 10 |
| Theoret. | | |
| | 250:750 | 250:750 |
| M.M. | 100 | 120 |
| S. | 366:634 av. 10 rdgs, mv 18 | 325:675 av. 12 rdgs, mv 6 |
| Theoret. | | |
| | 250:750 | 250:750 |
| M.M. | 140 | 160 |
| S | 380:620 av. 12 rdgs, mv. 20 | 400:600 av. 12 rdgs, mv. 24 |
| Theoret. | | |
| | 250:750 | 250:750 |

Iamb at tempos which increase by small intervals. Mean variation as usual.

| | | | | |
|---|---|---|---|---|
| M.M. | 40 | 50 | 60 | 72 |
| | 359:641 av. 10 rdgs | | 249:751 av. 10 rdgs | |
| | 360:640 10 | 409:591 av. 10 rdgs | 457:543 10 | 375:625 av. 10 |
| | 317:683 10 | 348:652 10 | 361:639 10 | 409:591 10 |
| Theoret. | | | 355:645 10 | 332:668 10 |
| | 250:750 | 250:750 | 250:750 | 250:750 |
| M.M. | 84 | 96 | 108 | 112 |
| | 351:649 av. 10 | 323:677 av. 10 rdgs | 409,591 av. 10 rdgs | 364:656 av. 10 |
| | 336:664 10 | 390:610 10 | 376:624 10 | |
| Theoret. | | 388:612 10 | 350:650 10 | |
| | 250:750 | 250:750 | 250:750 | |
| M.M. | 126 | 140 | | |
| | 340:660 av. 10 rdgs | 348:652 av. 10 rdgs | | |
| | 250:750 | 250:750 | | |

In the records of Table VI the short note of the unit-group is longer than the theoretical value; this is in accord with the records of other subjects. In the case of the slower tempos and occasionally at the higher tempos, the difference is large enough to be easily recognized by the ear.

It is apparent that the type of iamb may change, not only from subject to subject, but from time to time with the same subject; though the coördination is maintained when once established. For example in Table VI at M.M. 40, the type 260:740 is decidedly different from the type 360:640. So also at M.M. 60, type 250:750, type 460:540, and type 350:650 are decidedly different. The variation within each of such a series is slight, showing that the averages are not accidental.

Table VII shows the usual variations. M.M. 40 there are two types of iamb apparent, type 240:760, and type c.340:660. All the other figures are fairly uniform. With the exception of the single case just mentioned at M.M. 40, the averages show a type in which the short note is longer than the theoretical value.

## TABLE VII

***Subject T***

Iamb

Average of readings expressed as ratios

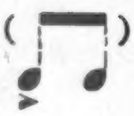
| M.M. | 40 | | 60 | | 80 | |
|---|---|---|---|---|---|---|
| | 243:757 | av. 11 rdgs, mv. 14 | 340:660 | av. 13 rdgs, mv. 27 | 248:752 | av. 13 rdgs, mv. 12 |
| | 358:642 | 10 | | | 242:758 | 10 |
| | 369:581 | 10 | | | 299:701 | 10 |
| | 300:700 | 6 | | | 313:687 | 10 |
| | 329:671 | 10 | | | 276:724 | 8 |
| | 343:657 | 7 | | | 357:643 | 9 |
| | 313:687 | 9 | | | | |
| | 331:669 | 10 | | | | |
| Theoret. | | | | | | |
| | 250:750 | | | | 250:750 | |

| M.M. | 100 | | 120 | |
|---|---|---|---|---|
| | 272:728 | av. 13 rdgs, mv. 9 | 300:700 | av. 11 rdgs, mv. 6 |
| | | | 283:711 | 10 |
| | | | 317:683 | 10 |
| | | | 290:710 | 10 |
| | | | 284:716 | 10 |
| | | | 287:713 | 11 |
| | | | 320:680 | 10 |
| | | | 309:691 | 9 |
| Theoret | | | | |
| | 250:750 | | 250:750 | |

| M.M. | 140 | | 160 | |
|---|---|---|---|---|
| | 342:658 | av. 12 rdgs, mv. 27 | 294:706 | av. 10 rdgs, mv. 18 |
| | | | 314:686 | 10 |
| | | | 347:653 | 10 |
| | | | 352:648 | 10 |
| | | | 385:615 | 10 |
| | | | 331:669 | 10 |
| | | | 327:673 | 10 |
| Theoret. | | | | |
| | 250:750 | | 250:750 | |

TABLE VIII

*Subject H*

Trochee doublet (  )

| | | | |
|---|---|---|---|
| MM. | 40 | 80 | |
| | 513:487 av. 8 rdgs, mv. 15 | 525:475 av. 7 rdgs, mv. 19 | |
| | 518:482 4 | 502:498 9 | |
| Theoret | | | |
| | 500:500 | 500:500 | |
| M.M. | 120 | 160 | 200 |
| | 509:481 av. 11 rdgs, mv. 9 | 440:560 av. 10 rdgs | 507:493 av. 10 rdgs |
| | 515:485 8 | 505:495 9 | |
| Theoret. | | | |
| | 500:500 | 500:500 | 500:500 |

*Subject S*

Trochee, doublet (  )

| | | |
|---|---|---|
| M.M. | 80 | 100 |
| | 580:420 av. 16 rdgs, mv. 17 | 540:460 av. 10 rdgs |
| Theoret: | | |
| | 500:500 | 500:500 |
| M.M. | 120 | 140 |
| | 509:491 av. 14 rdgs | 515:485 av. 14 rdgs |
| Theoret. | | |
| | 500:500 | 500:500 |

*Subject W*

Trochee, doublet (  )

| | | | |
|---|---|---|---|
| M.M. | 40 | 80 | 100 |
| | 512:488 av. 5 rdgs, mv 15 | 507:493, av. 8 rdgs, mv. 20 | 515:485, av. 14 rdgs |
| Theoret. | | | |
| | 500:500 | 500:500 | 500:500 |
| M.M. | 120 | 140 | |
| | 504:496 av. 16 rdgs | 529:471 av. 20 rdgs | |

In all the trochees of Table VIII the accented note is lengthened. This lengthening of the accented note has been frequently reported. The doublet does not vary as much from the theoretical

value as does the iamb. The variation from tempo to tempo and from sitting to sitting is probably due to the amount of accent thrown on the first note of the doublet; it is well known that an increase in the accent increases the length of the accented note.

TABLE IX

*Subject S*

Dactyl, triplet (  )

| | |
|---|---|
| M.M. 40 | 80 |
| 478:262:259 av. 7 rdgs, mv. 15 | 388:315:296 av. 7 rdgs, mv. 12 |
| Theoret. | |
| 333:333:333 | 333:333:333 |
| M.M. 100 | 120 |
| 343:326:329 av. 7 rdgs, mv. 14 | 343:328:329 av. 7 rdgs, mv. 16 |
| Theoret. | |
| 333:333:333 | 333:333:333 |
| M.M. 140 | |
| 345:334:321 av. 7 rdgs, mv 8 | |
| Theoret. | |
| 333:333:333 | |

*Subject W.*

| | |
|---|---|
| M.M. 40 | 80 |
| 374:359:269 av. 4 rdgs, mv. 6 | 344:335:321 av. 7 rdgs, mv. 5 |
| Theoret. | |
| 333:333:333 | 333:333:333 |
| M.M. 100 | 120 |
| 336:328:335 av. 5 rdgs, mv. 11 | 341:333:326 av. 14 rdgs, mv. 11 |
| Theoret. | |
| 333:333:333 | 333:333:333 |
| M.M. 140 | |
| 352:318:330 av. 4 rdgs, mv. 12 | |
| Theoret. | |
| 333:333:333 | |

Like the trochees, these dactyls of Table IX show the lengthening of the accented note. It is much more pronounced in some cases. The type is fairly well maintained in a given trial, as the mean variations show.

## *Discussion of Results*

It is rare indeed that the actual temporal relations of a musical iamb of the dotted-eighth-sixteenth form correspond at any tempo to the "theoretical value" of the notation. Not only do the individual unit-groups differ from this theoretical ratio, but the averages do not vary about this ratio as a norm. Only six series, involving sixty-one readings, out of seventy one series, involving one thousand fifty-two readings, show values near the theoretical value. These series whose averages are near the supposed norm are not to be found at any particular tempo, nor with any particular subject; they are infrequent and accidental.

In general the unaccented note of the iamb is decidedly longer than the theoretical value at all tempos and with all subjects. The type of the unit-group at a given tempo for a given sitting is fairly constant, as the mean variations show; but the type varies widely not only from subject to subject and from tempo to tempo, but also from sitting to sitting at the same tempo with the same subject.

The records of triplets and doublets show the usual lengthening of the accented note, when compared with the theoretical value. In the case of the iamb however the "lengthening" of the short unaccented note cannot be attributed to accent.

The results tend to show that the groupings of the fundamental rhythmic unit-groups are not a matter of quantitative time division; the sense of rhythm cannot be explained in terms of judgment of time intervals. Professionally trained subjects are unable to achieve the theoretical ratios. The types are much too variable; with these six musicians the records show time divisions for the dotted-eighth-sixteenth unit-group which vary all the way from the theoretical ratio 1 :3 through 1 :2 to 2 :3 and there is no preference for some simple ratio.

On the other hand, the grouping is not the random placing of some short before a long so that "the 'attention' subordinates the minor to the major element." The small variations show a precise movement type for each sitting. Some process makes the division fairly exact for each sitting.

The conception of a rhythmic unit-group as an organized group of movements whose conditions are muscular comes nearer to fitting the facts. It is quite possible to establish a coördination involving particular muscles and a particular stress on the accented beat which shall give precise movements during a single sitting. Since the movements are precise their time intervals are also fixed and regular. Changes of stress and of muscle group alter the type of unit-group. The limits of the variation of short and long in the musical iamb are the limits of the possible coordinations which give a satisfactory grouping of a light short pulse and a following heavy pulse into a single movement cycle.

# THE APPLICATION OF THE BINET-SIMON TESTS TO GROUPS OF WHITE AND COLORED SCHOOL CHILDREN*

George R. Wells

It has seemed to the writer that Oberlin offers a very fine opportunity to test the relative mental abilities of white and colored children. There is a fairly large number of colored children in the public schools of Oberlin, large enough to give some significance to a comparative test. The not unimportant part which Oberlin as a community and as a college has historically taken in the emancipation propaganda attracted many colored residents both before and after the war, a species of selection probably operating to choose the more intelligent and energetic members of the race. And the influences which attracted them were more or less effective to make the negroes welcome when they settled here, and to some extent, are still effective in the same way.

It has come about that at the present time colored residents are less set apart from white people than in most communities. The social environments of the two races are not as different as in practically all southern and most northern towns. The members of both races attend school, church and college on exactly the same terms. Of course this does not mean that the social environment of a colored family is identical with that of the average white family. But if the conditions for testing racial mental characteristics are not entirely free from the disturbances of environmental variations, they are perhaps as nearly free as we are apt to find anywhere in the country.

During the spring of 1914 an investigation was made of the relative mentality of the white and colored pupils in the public schools of Oberlin. In this investigation the writer was assisted by a group of his students from the Psychological Laboratory of

* The above article was written in 1915.

Oberlin College and by three members of the senior class of the Oberlin Kindergarten Training School, to all of whom acknowledgment is hereby made.

The tests applied were the ordinary Binet-Simon series. The form of test used was Huey's edition of Goddard's revision of the 1911 scale, as listed in the forms published by Warwick and York. The investigation was officially recognized by Superintendent Rawdon of the Oberlin Public School system. A room was placed at the disposal of the examiners at each of the three schools, and the pupils were sent from their class rooms to these examining rooms one by one. By this and other means it was possible to make the tests with very little distraction

Several problems of procedure arose early in the investigation. The period of testing covered several weeks, and, in spite of directions to the contrary, there is reason to believe that there was some little discussion of the tests among the pupils. There are two possible means of lessening, though not of eliminating, the effect of such discussion, assuming that it existed. In the first place, alternative questions could be, and were, used to some extent. But the limit of this method was soon reached. More to the point was the carefully carried out practice of having the tests on whites and blacks go on at the same time. White and colored children were examined in haphazard order. So that if any effect was produced by the conversation among the children concerning the tests there is no reason to suppose that it influenced one race more than another. The comparative value of the tests is certainly not affected by this influence.

Again it was found early in the tests that there was difficulty in the application of the fifteen year old test. For if a child passes the twelve year old test and fails in the fifteen year test there is some room for doubt as to how he should be classified. If there were thirteen or fourteen year tests the child might pass one or both of them. It is evident, I think, that mental age above twelve years can't be measured by the Binet-Simon scale. The following rules were adhered to in the calculation of the mental age after the tests has been administered.

1. All tests "over fifteen" were entirely neglected.

2. When the *mental age* of any child proved to be above twelve, no matter what his actual age, the card record of that case was discarded, and that record does not enter into the final results.

3. All cases of over twelve years *actual age* were likewise neglected unless the child failed in either the twelve year or in the eleven year tests.

4. If a child over twelve years actual age failed in the eleven or in the twelve year tests, the fifteen year tests were given. If successfully passed these counted as one additional year, or respective fraction thereof. But if the addition of this year made the mental age over twelve the card was thrown out as above stated.

5. No children under six years were included in the tests. The calculations of mental age were made by the writer and not in any case by the students engaged in making the tests.

Practically all white and colored children in the Oberlin Public Schools from six to twelve years of mental age were tested. The numbers actually recorded in the tables below, after eliminating all those affected by the rules just mentioned, were 96 negroes and 267 whites, the total number tested must have been half as many again.

In the following tables the figures represent percentages of the number of individuals involved, rather than actual numbers. This is done so that the difference in number of negroes and whites may be equalized. But for purposes of simplification one negro is counted as one percent of the total number of negroes instead of 1/96 of one percent, which is the strictly accurate figure. Likewise in the case of the whites concerned one case counts for 4/11 of one percent. As there are 267 whites concerned the absolutely correct figure would be 100/267 of one per cent, a rather unwieldly figure.

Table No. 1 shows the distribution of advancements and retardations for from six to twelve years mental age, with some cases running as high as sixteen years of actual age. The table

TABLE I

| | 6 Years | | 7 Years | | 8 Years | | 9 Years | | 10 Years | | 11 Years | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | W | N | W | N | W | N | W | N | W | N | W | N |
| ADVANCED | | | | | | | | | | | | |
| 4 | | | 4/11 | | | | | | | | | |
| | | | 4/11 | | | | | | | | | |
| | | | | | | | 4/11 | | | | | |
| 3 | | | 4/11 | | 4/11 | | | | | | | |
| | | | 4/11 | | 4/11 | | | | | | | |
| | | | 4/11 | | 4/11 | | | | | | | |
| | | | 8/11 | | 8/11 | | 8/11 | | | | | |
| | | | | 1 | | | 8/11 | | | | | |
| 2 | | | 1 9/11 | | 4/11 | | 1 1/11 | | 4/11 | | | |
| | | | 1 1/11 | | | | 1 1/11 | | | | | |
| | | 1 | 4/11 | 1 | 1 9/11 | | 1 5/11 | | | | | |
| | 4/11 | 1 | 4/11 | | 1 1/11 | | 8/11 | | 8/11 | | | |
| | | 1 | 8/11 | 1 | 4/11 | 1 | 2 2/11 | | 1 1/11 | 1 | | |
| 1 | 1 8/11 | | 8/11 | 1 | 4/11 | 1 | 4/11 | 1 | 4/11 | | 4/11 | |
| | 1 5/11 | | | 2 | 4/11 | 2 | 1 1/11 | | 2 6/11 | 1 | 8/11 | |
| | 8/11 | 1 | 8/11 | 1 | 4/11 | 4 | | | | 1 | 1 9/11 | |
| | | | 1 5/11 | 4 | 1 9/11 | 2 | 4/11 | | 1 5/11 | 3 | 2 10/11 | |
| | 4/11 | | 1 1/11 | | 8/11 | 2 | 1 1/11 | | 4/11 | 1 | 2 2/11 | |
| | 8/11 | 1 | 1 5/11 | 1 | 4/11 | | 8/11 | 2 | 1 1/11 | 2 | 1 9/11 | |
| | | | 1 1/11 | 2 | 8/11 | 2 | | 1 | 1 1/11 | 1 | 1 1/11 | 1 |
| | | | | 1 | 1 5/11 | | 4/11 | | 1 1/11 | 2 | 8/11 | |
| | | | | 1 | 8/11 | | 8/11 | 1 | 4/11 | 1 | 4/11 | 1 |
| | | | | | 4/11 | 2 | 4/11 | | | | | |
| 1 | | | 4/11 | | 4/11 | 1 | 4/11 | | 8/11 | | | |
| | | | | | | | 4/11 | | 8/11 | | | |
| | | | | | | | | | 8/11 | | | |
| | | | | | 4/11 | | | | 4/11 | 1 | 8/11 | 1 |
| | | | | | | | 4/11 | | 4/11 | | | 1 |
| 2 | | | | | | | | 1 | | | 4/11 | |
| | | | | | | | | | | | 4/11 | |
| 3 | | | | | | | | | | | | |
| | | | | | | | | | | | 4/11 | |
| 4 | | | | | | | | | | | | |
| | | | | | | | | | 4/11 | | | |
| 5 | | | | | | | | | | | | |
| RETARDED | | | | | | | | | | | | |

BLE I

| 1 Years W | 1 Years N | 12 Years W | 12 Years N | 13 Years W | 13 Years N | 14 Years W | 14 Years N | 15 Years W | 15 Years N | 16 Years W | 16 Years N |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4/11 | | | | | | | | | | | |
| 8/11 | | | | | | | | | | | |
| 9/11 | | | | | | | | | | | |
| 10/11 | | | | | | | | | | | |
| 2/11 | | 4/11 | | | | | | | | | |
| 9/11 | | 1 9/11 | | | | | | | | | |
| 1/11 | 1 | 8/11 | 1 | | | | | | | | |
| 8/11 | | 1 9/11 | 1 | | | | | | | | |
| 4/11 | 1 | 2 2/11 | | | | | | | | | |
| | | 1 5/11 | | | | | | | | | |
| | | | 3 | 8/11 | | | | | | | |
| | | | 2 | 4/11 | 1 | | | | | | |
| | | 4/11 | 1 | 1 9/11 | | | | | | | |
| 8/11 | 1 | 4/11 | 1 | 8/11 | | 4/11 | | | | | |
| | 1 | | 1 | 8/11 | | 4/11 | | | | | |
| 4/11 | | 4/11 | | 4/11 | 1 | 4/11 | | | | | |
| | | 4/11 | | 4/11 | 1 | 8/11 | | | | | |
| | | | 1 | 1 1/11 | 1 | 4/11 | | | | | |
| | | | | 8/11 | | 1 1/11 | 2 | | | | |
| 4/11 | | | | | | 8/11 | 2 | | | | |
| | | 4/11 | | | | 8/11 | 1 | | | | |
| 4/11 | | | | 4/11 | | 4/11 | 2 | | 2 | | |
| | | | | | | | 1 | | | | |
| | | | | | | | 1 | 4/11 | 1 | | |
| | | | | | | | 1 | 4/11 | | | |
| | | | | | 1 | | | | | | |
| | | | | | | 4/11 | | 4/11 | 1 | | |
| | | | | | | | | | 1 | | |
| | | | | 4/11 | | | | | | 4/11 | |
| | | | | | | | | | 1 | 4/11 | |
| | | | | | | | | | 1 | | 1 |

TA

| | | 6 W | 6 N | 7 W | 7 N | 8 W | 8 N | 9 W | 9 N | 10 W |
|---|---|---|---|---|---|---|---|---|---|---|
| RETARDED | 3 to 4 years | | | $^{8}/_{11}$ | | | | $^{4}/_{11}$ | | |
| | 2 to 3 years | | | $1^{9}/_{11}$ | 1 | $1^{9}/_{11}$ | | $1^{5}/_{11}$ | | |
| | 1 to 2 years | $^{4}/_{11}$ | 3 | $4^{4}/_{11}$ | 2 | $3^{7}/_{11}$ | 1 | $6^{6}/_{11}$ | | $2^{2}/_{11}$ |
| | to 1 year | 4 | 1 | 4 | 8 | $3^{7}/_{11}$ | 11 | $2^{10}/_{11}$ | 1 | $4^{8}/_{11}$ |
| | Normal | $^{8}/_{11}$ | 1 | $1^{5}/_{11}$ | 1 | $^{4}/_{11}$ | | $^{8}/_{11}$ | 2 | $1^{1}/_{11}$ |
| ADVANCED | to 1 year | | | $1^{5}/_{11}$ | 4 | $3^{7}/_{11}$ | 5 | $1^{9}/_{11}$ | 2 | $3^{3}/_{11}$ |
| | 1 to 2 years | | | | | $^{4}/_{11}$ | | $^{8}/_{11}$ | 1 | $2^{2}/_{11}$ |
| | 2 to 3 years | | | | | | | | | |
| | 3 to 4 years | | | | | | | | | |
| | 4 to 5 years | | | | | | | | | $^{4}/_{11}$ |
| | 5 to 6 years | | | | | | | | | |

TABI

| | 6 W | 6 N | 7 W | 7 N | 8 W | 8 N | 9 W | 9 N | 10 W |
|---|---|---|---|---|---|---|---|---|---|
| Advanced | $4^{4}/_{11}$ | 4 | $10^{10}/_{11}$ | 11 | $9^{1}/_{11}$ | 12 | $11^{3}/_{11}$ | 1 | $6^{10}/_{11}$ |
| Normal | $^{8}/_{11}$ | 1 | $1^{5}/_{11}$ | 1 | $^{4}/_{11}$ | | $^{8}/_{11}$ | 2 | $1^{1}/_{11}$ |
| Retarded | | | $1^{5}/_{11}$ | 4 | 4 | 5 | $2^{6}/_{11}$ | 3 | $5^{9}/_{11}$ |

TABI

| | 6 W | 6 N | 7 W | 7 N | 8 W | 8 N | 9 W | 9 N | 10 W | 10 N |
|---|---|---|---|---|---|---|---|---|---|---|
| Advancement Units | 13 | 7(19) | 58 | 15(41) | 45 | 13(36) | 60 | 1 (3) | 25 | 8(2 |
| Retardation Units | | | 4 | 4(11) | 12 | 5(14) | 9 | 4(11) | 26 | 6(1 |

TABLE II

| N | 10 W | 10 N | 11 W | 11 N | 12 W | 12 N | 13 W | 13 N | 14 W | 14 N | 15 W | 15 N | 16 W | 16 N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $2\,^{2}/_{11}$ | 1 | | | | | | | | | | | | |
| 1 | $4\,^{8}/_{11}$ | 6 | 8 | | $^{4}/_{11}$ | | | | | | | | | |
| 2 | $1\,^{1}/_{11}$ | 2 | $1\,^{9}/_{11}$ | | $1\,^{9}/_{11}$ | | | | | | | | | |
| 2 | $3\,^{3}/_{11}$ | 4 | $2\,^{2}/_{11}$ | 2 | $6\,^{2}/_{11}$ | 5 | $^{8}/_{11}$ | | | | | | | |
| | $2\,^{2}/_{11}$ | 1 | $1\,^{1}/_{11}$ | 2 | $1\,^{1}/_{11}$ | 5 | 4 | 2 | $1\,^{1}/_{11}$ | | | | | |
| | | | $^{8}/_{11}$ | | $^{8}/_{11}$ | 1 | $2\,^{2}/_{11}$ | 2 | $3\,^{7}/_{11}$ | 5 | | | | |
| | | | $^{4}/_{11}$ | | | | $^{4}/_{11}$ | 1 | $^{4}/_{11}$ | 5 | $^{8}/_{11}$ | 3 | | |
| | $^{4}/_{11}$ | | | | | | $^{4}/_{11}$ | | $^{4}/_{11}$ | | $^{4}/_{11}$ | 3 | $^{8}/_{11}$ | |
| | | | | | | | | | | | | 1 | | 1 |

TABLE III

| 10 W | 10 N | 11 W | 11 N | 12 W | 12 N | 13 W | 13 N | 14 W | 14 N | 15 W | 15 N | 16 W | 16 N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $6\,^{10}/_{11}$ | 7 | 8 | | $^{4}/_{11}$ | | | | | | | | | |
| $1\,^{1}/_{11}$ | 2 | $1\,^{9}/_{11}$ | | $1\,^{9}/_{11}$ | | | | | | | | | |
| $5\,^{9}/_{11}$ | 5 | $4\,^{4}/_{11}$ | 4 | 8 | 11 | $7\,^{7}/_{11}$ | 5 | $5\,^{5}/_{11}$ | 10 | $1\,^{1}/_{11}$ | 7 | $^{8}/_{11}$ | 1 |

TABLE IV

| 10 W | 10 N | 11 W | 11 N | 12 W | 12 N | 13 W | 13 N | 14 W | 14 N | 15 W | 15 N | 16 W | 16 N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 8(22) | 22 | | 1 | | | | | | | | | |
| 6 | 6(16) | 22 | 6(16) | 29 | 18(49) | 51 | 14(38) | 45 | 35(96) | 13 | 33(91) | 10 | 6(16) |

shows advancements and retardations in terms of 1/5 years, after the familiar Binet-Simon method.

Table No. 2 is inserted for purposes of convenience to provide a summary of Table 1. The figures are the same as in the first table except that they are for years, instead of for fifths of years.

Table No. 3 is a summary of the total percentages retarded, advanced and normal for both races. Inasmuch as only those were counted normal who were exactly at the age level to the fifth of a year, the number seems small. The reckoning of the actual age of the children in fifths of a year was done easily and accurately by consulting the school records of the date of birth.

A view of the final results is given in Table No. 4, which is so arranged that at a glance one may observe the relative results from the two races, without being confused by the fact that there were about two and a half times as many whites as negroes concerned in the tests. Also the total amount of retardation is indicated, as well as the number retarded. These are two different things, for while one race might have more actual cases of retardation than the other, in the case of the second race the degree of retardation in the cases of those who were backward might be comparatively very high. Therefore the Table is an arrangement of what may be called "retardation units." A "retardation unit" may be considered as one case retarded for one year or for part of one year. Thus the retardation of a child three years behind his age level would be recorded as three units. "Advancement units" are reckoned in a similar way. The figures which give the units of retardation and advancement for the negroes are followed by other figures in brackets. These bracketed figures are the numbers of units earned by the negroes multiplied by 11/4. The figures thus obtained are directly comparable with the number of units earned by the whites, and enables the reader easily to compare the performances of the two races.

If these results are carefully examined it will be seen that the whites make, in the whole, a little the better showing. The great-

est advancement reckoned in terms of averages is white, and the individuals which were most advanced were white. On the other hand the greatest retardation in point of averages, and the most retarded individuals were negroes. The arrangement in terms of retardation units is still more strongly indicative of an advantage on the part of the whites. The total number of retardation units on the part of the whites is 221, and on the part of the negroes is 358. The advancement units for the whites number 224, and for the blacks 121. In both of these cases the figures given for the negroes is that obtained by the equalization process of multiplying the actual number of negro units by 11/4. Judging by any of these Tables there is a small but not insignificant advantage in favor of the whites.

But far more important than the mere fact of a better showing made by one of the racial groups is the arrangement of the results as regards ages. It is very noticeable that the negroes are at least equal to the whites at the ages of six, seven, and eight. Nor are the negroes very markedly inferior to the whites at the ages of nine, ten and eleven. At twelve years there is a marked difference, and it becomes progressively more marked from twelve to sixteen, reaching its climax at fourteen and fifteen. Evidently the children start in on equal terms, and maintain that equality for some years. But gradually the negroes lag behind, and at about the age of finishing grammar school or entering high school seem to be definitely inferior to the whites. There are, of course, many exceptions. These results are to be understood as averages of performances of a moderately large number of school children. Their significance must not be mistaken nor exaggerated. But it seems to be beyond doubt that under the conditions mentioned, and using the tests which we used there is no difference in the reactions of white and colored children up to the age of ten or eleven. At the age of twelve a difference is noticeable, which difference becomes very prominent at fourteen, fifteen and sixteen years of age. That the negroes are outstripped seems undeniable.

It remains to determine the cause of this difference. The simplest explanation and that which comes first to one is that

it is a manifestation of some inherent mental superiority of the white race over the negro. But it seems evident to the writer that such an explanation can not be applied in this specific case. One reason will sufficiently dispose of it, and that is the impossibility of determining the purity of blood of many negroes. Beyond all doubt most, if not all, of the colored children examined have some mixture of white blood, in proportions impossible to determine.

The correct explanation will probably be found when the social conditions and limitations of the two races are examined. Mr. Howard L. Rawdon, the Superintendent of the Oberlin School System, has gone into the question of the social differences confronting the two races in a report presented to the Department of Education of Oberlin College and entitled "The Colored Pupil in the Oberlin Public Schools." He points out that the limitation of possible professions for negroes is so great that there is smaller incentive to continue at school than operates in the case of the white children. He also shows that the economic position of the negroes in Oberlin is not good. The colored people constituted something more than 18% of the population of Oberlin in 1913, but owned no more than 4% of the taxable property. And what is still more significant is the fact that less than 7/10 of one percent of the personal property is owned by negroes. The percapita wealth of the whites is more than five times that of the colored people. Further, records of crime in Oberlin show that the colored people are responsible for far more than their share, calculated on their proportion of population. And this criminal tendency becomes even more marked if serious crimes only be considered, and mere violations of local ordinances be neglected.

The social and moral conditions so briefly mentioned above may properly be held responsible for the very great irregularity of school attendance and for the large amount of tardiness in the case of negro children in general. Mr. Rawdon states that the school records show that the colored pupils are absent practically fifty percent more than the white pupils, and that the boys

are absent oftener than the girls, the reverse of the case with the whites. It is also very significant that the colored pupils drop out of school much earlier than do the whites. For instance, in the four lower grades 27.4 % of the enrollment is colored; in the four upper grades, 21.8% and in the High School but 10.3 % are colored. No doubt much of this absence and early leaving of school is due to economic pressure driving the children to work, much of it is also due to the generally unpromising outlook for the colored student, even if he does graduate from High School. And to this latter cause and the unambitious attitude it engenders is due the excessive amount of tardiness, which Mr. Rawdon also notes.

The writer feels that the probability is that the disparity in performance between the groups of white and colored children which he and his assistants tested is due to social and environmental factors rather than to inherited or racial traits of mental ability.